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NAVIGATIONAL COMPASSES

GYRO versus MAGNETIC.

By C. HUEY, Civil Member,* and C. E. TAYLOR.†

The word *compass* comes from Old French, compass, a measure, derived from a verb of latin type, *compassare*, to measure off with steps (passus, step). Before the advent of the *gyro compass*, a compass was defined as an instrument to indicate the *magnetic* meridian or position of objects with reference to it. Consideration of the gyro compass requires that the definition be extended to include an instrument which indicates the *geographical poles* or the axis of the earth's rotation. The foregoing old definition and its extension, indicates the basic distinction between the two fundamental compasses *e.g.*, the magnetic compass and the gyro compass.

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HISTORICAL.

The Magnetic Compass.—The origin of the magnetic compass is very uncertain and is more or less disputed. Most writers credit the Chinese with the first compass, dating back to about 2000 years B. C. The Chinese are said to have used a magnetic *loadstone* to guide their land conveyances on long journeys when fog obscured the sun or stars. In the year 1242 A. D., Bailak Kibjaki described a primitive type of compass then in use on the Syrian coast. Marco Polo, the Italian, on his return from Cathay (China) in 1295 A. D., brought with him several Chinese inventions and a description of a compass. The first type of magnetic compass was said to consist of a magnet floating on reeds in a basin of water. The early Italians probably made the suspension of the magnet more practicable by mounting it on a vertical pivot. Later, a circular card marked with a *rosa ventorium* or "rose of the winds," was placed on the magnet to indicate the various points of the compass (see Plate A). Other forms of historical compass cards are also shown which indicate that, in general, the layout of the modern card based on the cardinals, north, east, south, and west, and the intercardinals, northeast, southeast, southwest, and northwest, still follow the practice originated in medieval times. The modern ship's magnetic compass, however, has been greatly improved in the quality, permanency, and strength of the magnets.

The Navy Standard Liquid Compass.—This magnetic compass consists of a skeleton card 7½ inches in diameter made of non-magnetic metal to which four parallel magnets are symmetrically attached. The whole rests on a bell-metal pivot against a sapphire cap in a low freezing point damping liquid consisting of 45 per cent alcohol and 55 per cent distilled water. The magnet system of the card consists of four cylindrical bundles of steel wires. These wires are laid side by side and magnetized as a bundle between the poles of a powerful electro-magnet. They are afterwards placed in a cylindrical brass case, sealed and secured to the card. Steel wire made up into a bundle is used because it is more homogeneous, can be more perfectly tempered, and for the same weight, gives greater magnetic power than a solid steel bar. Also in the form of wires, it is practical to balance the magnetic strength of the four

magnets to obtain magnetic symmetry by increasing or decreasing the number of wires in the individual bundles, or, by reversing the positions of one or more wires in a bundle, to decrease its total strength.

The card is provided with an air vessel to buoy its own weight and that of the magnets to an allowable pressure of between 60 and 90 grains. The mechanism and liquid are contained in a brass bowl with a suitable expansion chamber which keeps the chamber full regardless of the contraction or expansion of the liquid due to changes in temperature. The bowl is covered with thick glass sealed by a rubber gasket to prevent leakage or evaporation. The compass bowl is mounted in gimbals on knife edges in the stand or binnacle (see Plate A). The complete binnacle (see Plate B) contains compensating magnets to off-set the magnetic effect of iron in the hull, cargo or equipment of the ship. Also attached to the binnacle and extending from its sides are two soft iron adjustable spheres which compensate a quadrantal deviation caused by the earth's magnetism acting on the *horizontal* soft iron of the ship.

The Gyro Compass.—The word *gyro* or *gyroscope* was coined by the French physicist Foucault, to illustrate the rotation of the earth. It was derived from two Greek words *guros,* meaning tour or revolution, and *skopein,* meaning, to view. The literal translation of the combined words is, to view the revolution of the earth. Sometime in the eighteenth century, the rotating wheel, which is the basis of the gyroscope, was invented by the French or Germans, but the first mention of it is not made until 1817, by Bohenberger, a German.

Foucault, a Frenchman, is given the credit for making exhaustive experiments in 1852 with a freely suspended rotating wheel. He gave it the name *gyroscope* for the reason, as stated by him, that "its gyrations depend upon the rotation of the earth and are but varied manifestations of such rotation." It is understood that the experiments as conducted by Foucault were actually suggested by Lang, of Edinburg, Scotland, in the year 1836, but were not tried by him.

The scientific meaning of the word gyroscope is a rotating wheel so suspended as to be free to move about any axis, or a wheel having freedom in three planes. Foucault in making his

observations and demonstrations worked under considerable difficulties, due to not being able to have a wheel turn at a constant speed for an indefinite length of time. He was only able to set a wheel in motion by winding up a string or some similar device and the wheel would run only for a short period of time and at very low speeds. In 1878, about twenty-six years after Foucault's observations and experiments, an American, named Hopkins, built an electric motor to function with Foucault's gyroscopic apparatus, thereby securing more definite results than had been obtained up to that time.

About 1900, Dr. Anschutz, a German, started to experiment with the gyroscope and in 1906 he designed a gyro compass that would seek the meridian, but would not cease oscillating. In 1908, Dr. Anschutz perfected a gyro compass which would come to rest and his gyro compass was tested on the German battleship *Deutschland*. In 1909 an Anschutz compass was demonstrated to the United States Navy on the U. S. S. *Birmingham*. The British Navy tried out the Anschutz gyro compass in 1910.

After many years of research, the date of the beginning not being recorded, Dr. Elmer A. Sperry, an American, developed a gyro compass which was placed on the Old Dominion S. S. *Princess Anne* in the Summer of 1911 and made several trips between New York and Norfolk. It was removed from this ship in the Fall of 1911 and was placed on the U. S. S. Battleship *Delaware*. After several trial runs, it was accepted by the United States Navy, and to this date the Sperry gyro compass, manufactured by the Sperry Gyroscope Company, Inc., is being supplied to the United States Navy.

Sometime in 1917, the Carrie Gyroscope Corporation, holding certain gyro compass patents invented by an American by the name of Carrie, received a contract from the United States Navy to furnish a gyro compass. The exact date is not known when he started the development. After three years, the Carrie Gyroscope Corporation which was organized to manufacture the gyro compass, defaulted due to not being able to produce a compass which would pass the required United States Navy test specifications.

Then the Arma Engineering Company, composed of American Engineers, about the year of 1919, received from the United States

Navy a contract to develop a gyro compass. The gyro compass as designed by them passed the required United States Navy test specifications, and since that time the Arma Engineering Company has been supplying the United States Navy with compasses in competition with the Sperry Gyroscope Company.

S. G. Brown, an Englishman, in 1921 submitted a gyro compass to the English and the United States Navies, but it was not accepted by the United States Navy as it did not pass the required United States Navy test specifications.

In 1922 a gyro compass was submitted to the United States Navy by Ernest Hendstrom, of Swedish descent; this gyro compass also failed to pass the required United States Navy test specifications and was not accepted.

Comparison of the Magnetic and the Gyro Compass.—Navigational work is based on geographical meridians of longitude running north and south, and parallels of latitude running east and west. Any form of compass which would indicate without error, either meridians or parallels when observed from any point on the surface of the earth under all conditions, would be the ideal, at present unattainable. The errors of the magnetic compass are divided into two classes: one, the error caused by the earth's magnetic lines not being coincident with the geographic meridian, termed "variation," and the other, the error caused by iron in the ship magnetized by the earth's magnetism or by local influences, termed "deviation."

The Variation Error of the Magnetic Compass.—The earth's magnetic *south* pole toward which the *north* pole of the compass magnet is attracted in accordance with the laws of magnetized bodies, is located in the upper part of Canada about 600 miles from the geographic north pole, in an area of appreciable size. The compass magnet, if free from other magnetic forces, points in a general direction toward this area. The angle representing the difference between this magnetic meridian and the true north, is the *variation*. This difference varies according to geographical localities. Charts of variation are issued by the Government Hydrographic Office periodically for the reason that the magnetic pole area has slow wandering characteristics which necessitates chart revision. A section of the 1930 chart showing the variation, is

shown in Plate C. In order to obtain true geographical direction observations with the magnetic compass, the geographical position of the observer on the earth's surface must be known approximately so that the variation as shown by the chart, may be used to correct the observation.

The second source of the magnetic compass error, caused by magnetic materials in the ship, has many ramifications. Deviation from the magnetic meridian from this cause varies greatly at different latitudes, due to the decreasing *horizontal* and increasing *vertical* magnetic force component at the higher latitude, *e. g.*, near the earth's magnetic pole area. The hardened steel material of the ship tends to become permanently magnetized by the earth's magnetic field, while with the soft iron parts, the magnetism is more of a transient nature. In combination, the resulting deviations of the magnetic compass are of a varying nature which cannot be compensated by any permanent adjustment of the compensating magnets or soft iron shielding spheres.

Uses of the Magnetic Compass.—However, due to the simplicity of the magnetic compass in its freedom from electrical windings, devices, etc., and the utter absence of moving parts other than the slow moving sensitive element, it continues to be generally used on all Naval vessels, and as a *stand-by* compass for all Naval ships equipped with gyro compasses.

The Superiority of the Gyro Compass.—The superiority of the gyro compass over the magnetic compass is based on the principles under which it obtains its directive force. The force is derived from the combined effects of the rotation of the earth and of gravity, on a spinning wheel of sufficient speed and mass to give the resultant directive force desired. The explanation of how these forces of nature are employed, are taken up in subsequent pages. The inherent advantages of the gyro compass over the magnetic compass, from fundamental standpoints, may be itemized as follows:

(*a*) It seeks the true geographical north, *e. g.*, the axis of the earth's rotation.

(*b*) It requires no magnetic deviation chart.

(*c*) It is not influenced by permanent or transient magnetism of the ship.

(*d*) It is not influenced by any change in the character or disposition of the cargo or equipment of the ship.

In other words, the gyro compass functions entirely from mechanical forces, as compared with the magnetic compass which functions entirely from magnetic forces.

The Premium Paid for Using Gyro Compasses.—Of course, in the employment of mechanical forces as the operating principle of the gyro compass to obtain superior fundamentals, a heavy premium is paid in terms of mechanical parts and in electrical equipment employed to obtain necessary mechanical forces. Likewise, premium is paid in complication and devices to compensate or correct for mechanical forces superimposed on the gyro compass by the movements of the ship. This is discussed in subsequent pages. Also, similar to the magnetic compass which requires that the approximate location of the ship on the earth's surface be known so that the deviation chart may be used for correction, it is likewise required that the ship's *latitude* location be known within three degrees when using the gyro compass so that the mechanical forces of the ship's movement may be correctly balanced in terms of the decreasing speed of the earth's surface as it approaches the geographic poles. This, however, becomes a matter of mathematical corrections which are as permanent as the laws governing the earth's rotation. This is also discussed in subsequent pages.

The Necessity of the Gyro Compass.—Regardless of the extensive equipment required, and the very special training required to adjust and maintain the accuracy of the ship's gyro compass, both of which items are conceded to involve more mechanical and electrical principles than any other one device in Naval Service, the gyro compass has become an absolute necessity for its application to navigational purposes and in its extension into the field of gunfire control, automatic course recording and automatic steering. The fundamentals which hold its superiority over the magnetic compass are based on its geographical directional properties, and its freedom from local or transient magnetic errors.

THEORY OF THE GYRO COMPASS.

The fundamental principles which cause the gyro compass to function, are probably more complicated and generally less known

than any other device used in Naval Service. However, for those whose minds are adapted along mechanical lines, and who can absorb the perspective of motion in *three* planes when necessarily illustrated on paper in *one* plane, the principles of operation, although involved and somewhat startling in certain aspects, may be satisfactorily portrayed, if taken step by step.

The Elementary Gyroscope.—The gyroscopical phenomena are best explained and illustrated by the use of an elementary *gyroscope* of which the toy demonstrating form is the best in the point of resemblance to the gyro compass. This device shown in Figure 1, consists of a balanced wheel, free to spin with its axle in any direction relative to space. It has three planes of freedom, *viz.*—(1) wheel spins upon *its own axle*; (2) wheel and pivot ring turn about a *horizontal axis*; (3) wheel, pivot ring and vertical (half) ring turn about a *vertical axis*. All parts are so adjusted that a perfect balance exists about each of the three axes.

Gyroscopical Properties.—If the balanced wheel of the elementary gyroscope is arranged to be spun in either direction, and if the supporting axes have complete freedom, and are sufficiently frictionless, this device may be used to demonstrate the two basic gyroscopical phenomena, namely:

(*a*) *Rigidity* of the wheel *in space.*

(*b*) *Precession* or wandering of the wheel axis in space, when certain *external* forces are applied.

Rigidity.—Rigidity, relative to space, is illustrated in Figures 2(a) and 2(b). Here, it is shown, that while the wheel is spinning, the supporting frame may be carried about at any angle, without alteration of the direction of the wheel axis *relative to space.* This phenomenon is an application of Newton's First Law of Motion which states that "a body continues at rest or of uniform motion in a straight line, unless changed by an externally applied force." This law applied to a rotating wheel, is expressed by stating that, "the wheel tends to maintain the direction of its *plane* of rotation, and axis, *in space.*"

To further illustrate the *rigidity* phenomenon, the gyroscope is assumed to be placed on the equator of the earth, see Figure 3, with the axis of the wheel horizontal to the earth's surface in an

east and *west* direction as shown in position zero (0). The other positions of the wheel marked 3, 6, 9, 12, 15, 18, and 21, show the positions to which the wheel would be carried by the gyroscope support secured to the earth's surface, at the different periods corresponding to the 24-hour daily rotation of the earth. The wheel, while maintaining the rigidity of its plane of rotation relative to space, has made one complete end-over-end rotation with respect to the earth.

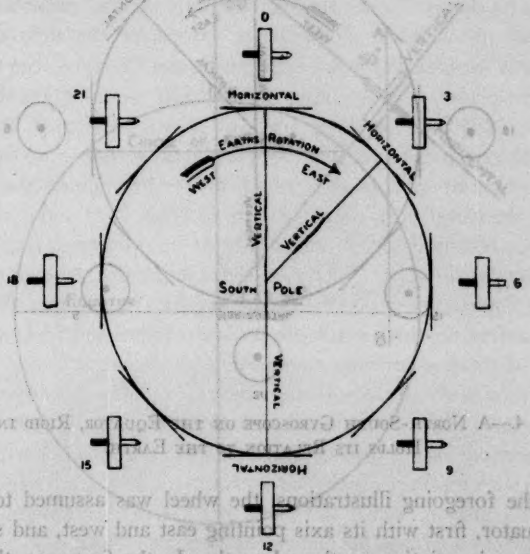


FIGURE 3.—AN EAST-WEST GYROSCOPE ON THE EQUATOR ALTHOUGH RIGID IN SPACE, TURNS END-OVER-END WITH RESPECT TO THE EARTH.

If the gyroscope is again assumed to be placed on the equator in the same manner as in Figure 3, but with the axis of the wheel pointing north and south, as indicated in Figure 4, no directional change of the wheel *axis* is apparent during the 24-hour period. The gyroscope wheel has simply been carried around in space with the wheel always in the *plane of its rotation.* Again, the wheel has maintained its rigidity in space, but due to the initial *north* and *south* direction of its axis, the *plane* of the wheel has moved in

the *plane* of the earth's rotation. Therefore, relative to the earth, the wheel direction has not changed during the rotation of the earth.

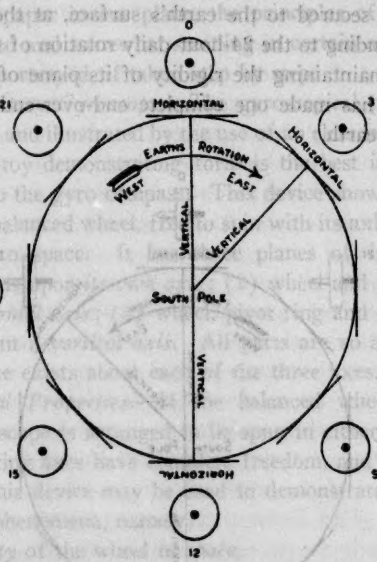


FIGURE 4.—A NORTH-SOUTH GYROSCOPE ON THE EQUATOR, RIGID IN SPACE, HOLDS ITS RELATION TO THE EARTH.

In the foregoing illustrations, the wheel was assumed to be at the equator, first with its axis pointing east and west, and second, with its axis pointing north and south. In the first case, the axis made a *vertical* turn over of one revolution in relation to the earth. In the second case, the direction of the axis remained unchanged. It may be perceived, by referring to Figure 5, that if the gyroscope be placed at some position north (or south) of the equator, with the initial direction of the axis of the wheel in some direction other than parallel to the earth's *axis*, then the apparent movement of the axis of the wheel will be an angular rotation in the vertical and horizontal, around the line AB. If placed horizontal *at the earth's poles*, the wheel axis will make an apparent *horizontal* revolution with respect to the earth. The fact has now been established that

a completely free gyroscope may be moved anywhere, or be carried around by the earth's rotation, without altering the direction of its wheel axle *relative* to *space*. However, *relative to the earth's surface*, the direction of the wheel axle has certain angular rotations depending on its initial direction, and *latitude* (north or south angular distance from the equator).

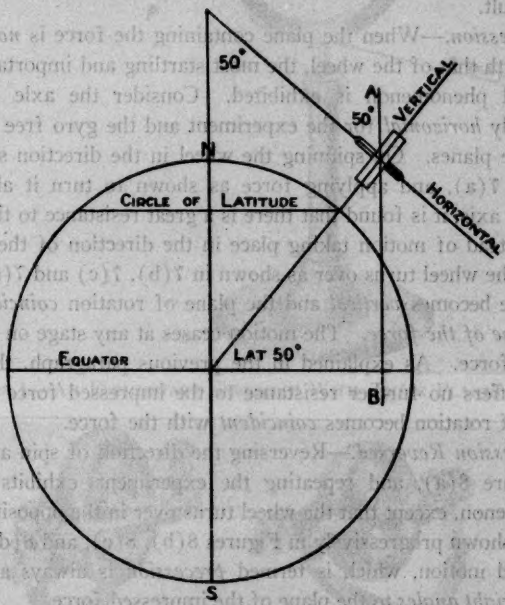


FIGURE 5.—ANGULAR ROTATION OF A GYROSCOPE AXLE WHEN NOT LOCATED ON THE EQUATOR.

Angular Forces.—In the foregoing, the forces moving the gyroscope are termed *linear forces* or forces of translation, that is, motion in which *all* the parts follow the same direction. The effect, however, of *angular* forces, or rotation forces acting directly upon the gyro wheel, is quite different, and gives rise to phenomena known as *precession*, or *wandering* of the wheel axle direction in space. The plane containing the angular force may be coincident with the plane of the gyro wheel, or it may be in any direction,

When it coincides with the plane of the wheel, as seen in Figure 6(a) in which the axle is vertical, any effort to turn the gyro about the vertical axis as shown in Figure 6(b), *meets with no resistance,* and the gyro frame responds readily to the touch. If the *plane* of the force and that of the wheel rotation are truly parallel, the direction of the wheel rotation makes no difference whatever in the result.

Precession.—When the plane containing the force is *not* coincident with that of the wheel, the most startling and important gyroscopical phenomenon is exhibited. Consider the axle set conveniently *horizontal* for the experiment and the gyro free to move in three planes. On spinning the wheel in the direction shown in Figure 7(a), and applying force as shown to turn it about the vertical axis, it is found that there is a great resistance to the force, and instead of motion taking place in the direction of the applied force, the wheel turns over as shown in 7(b), 7(c) and 7(d), until the axle becomes *vertical* and the plane of rotation *coincides with the plane of the force.* The motion ceases at any stage on removal of the force. As explained in the previous paragraph, the gyroscope offers no further resistance to the impressed force once its plane of rotation becomes *coincident* with the force.

Precession Reversed.—Reversing the direction of spin as shown in Figure 8(a), and repeating the experiment, exhibits similar phenomenon, except that the wheel turns over in the opposite direction as shown progressively in Figures 8(b), 8(c), and 8(d). The observed motion, which is termed *precession* is always about an axis at *right angles* to the plane of the impressed force.

Rule for Precession.—By comparing the final positions, 7(d) and 8(d), it will be seen that the wheel not only sets its plane of rotation into coincidence with the force, but that the *direction of wheel spin,* is also coincident. The foregoing experiments may be varied in many positions and planes. The same results may be expressed by the rule "when a gyroscope is subjected to an angular force not coincident with the plane of wheel rotation, the force meets with great resistance and the gyro wheel turns about an axis at right angles to the plane of the force, the movement being such as to place the wheel coincident with the plane and direction of the force *by the shortest path*" (the 90-degree path rather than the 270-

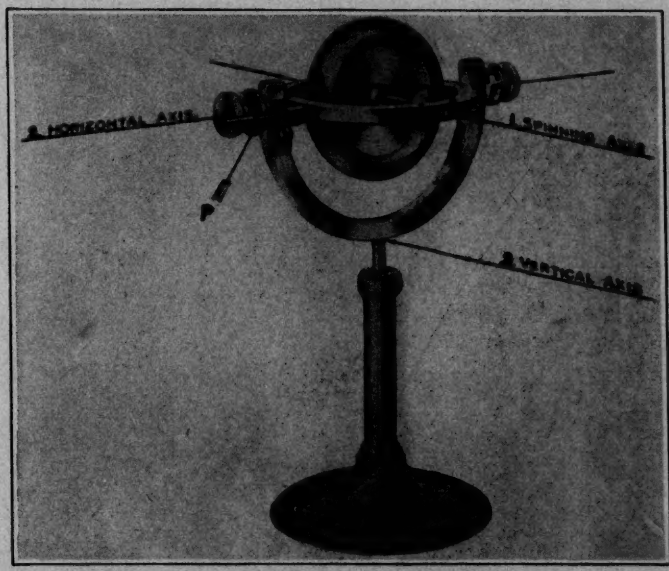


FIGURE 1.—AN ELEMENTARY GYROSCOPE WITH THREE PLANES OF FREEDOM.

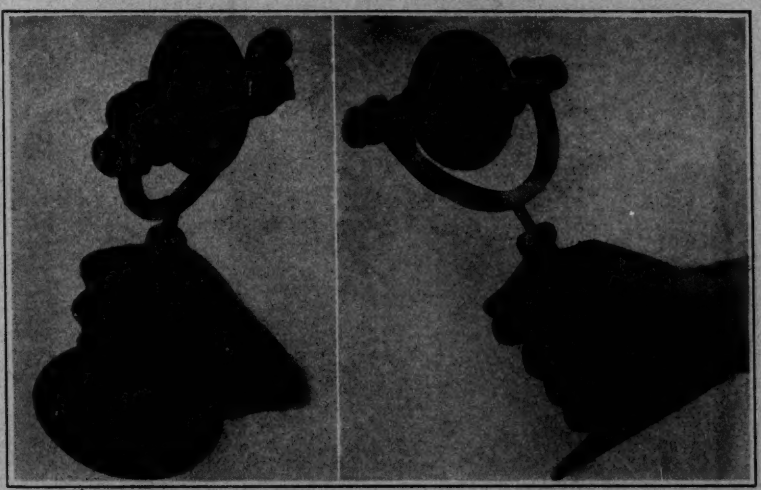


Fig. 2 (a). Fig. 2 (b).

FIGURES 2 (a) and 2 (b).—ILLUSTRATING THE RIGIDITY IN SPACE OF A WHEEL.

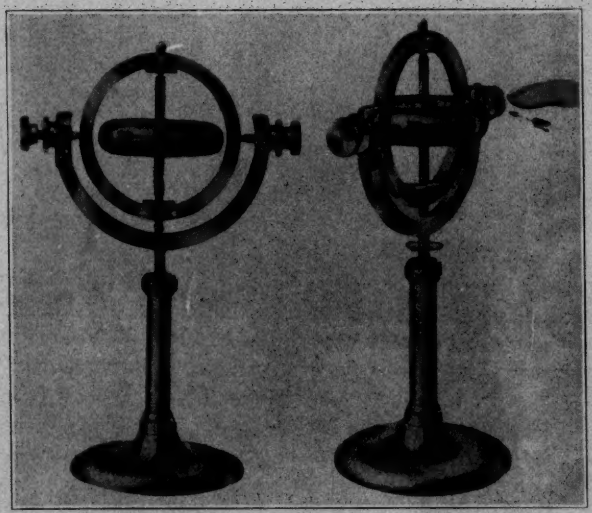


Fig. 6 (a). Fig. 6 (b).

FIGURES 6 (a) and 6 (b).—AN EXTERNAL FORCE APPLIED IN THE PLANE OF THE WHEEL MEETS NO RESISTANCE.

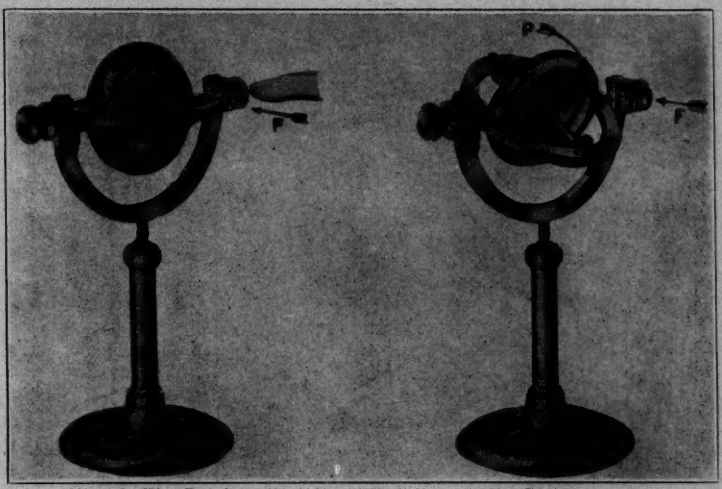


Fig. 7 (a). Fig. 7 (b).

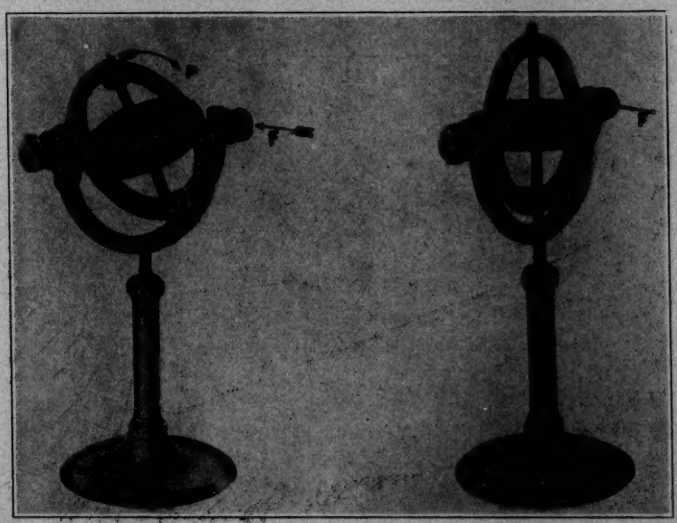


Fig. 7 (c). Fig. 7 (d).

FIGURES 7 (a), 7 (b), 7 (c) and 7 (d).—AN EXTERNAL FORCE APPLIED AT A RIGHT-ANGLE TO THE PLANE OF THE WHEEL, TURNS OR PRECESSES THE WHEEL UNTIL THE PLANE OF THE WHEEL COINCIDES WITH THE PLANE OF THE FORCE.

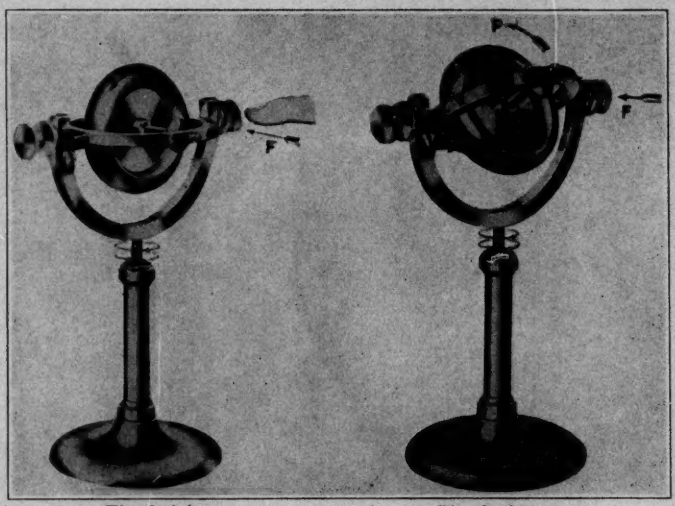


Fig. 8 (a). Fig. 8 (b).

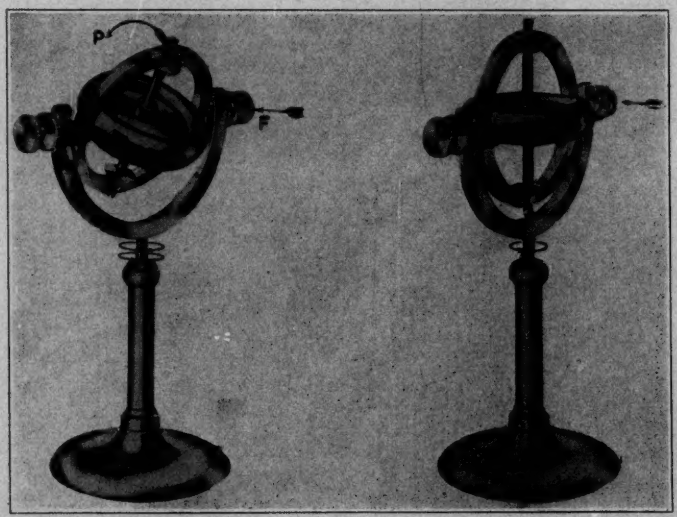


Fig. 8 (c). Fig. 8 (d).

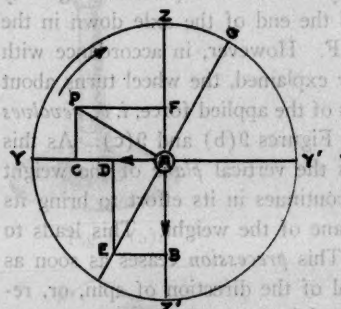
FIGURES 8 (a), 8 (b), 8 (c) and 8 (d).—REVERSING THE WHEEL SPIN, REVERSES THE DIRECTION OF PRECESSION. THE PLANE OF THE WHEEL AND DIRECTION OF SPIN AGAIN COINCIDE WITH THE PLANE OF THE FORCE AS IN FIGURE 7 (d).

degree path). The resistance to the force and the resulting precessional effect are greatest when the plane of the force is at *right angles* to the plane of the wheel.

Continuous Precession.—When the force acting on the gyro system is arranged in such a way that it, and the *plane containing* the *force,* is caused to rotate *with the precession,* the latter becomes *continuous.* This is demonstrated in Figures 9(a), 9(b), and 9(c), showing a spinning gyro with horizontal axis, with a weight hung at one end of the axis. Ordinarily it would be expected that gravity acting on the weight would pull the end of the axle down in the direction of the arrow marked F. However, in accordance with the *rule of precession* previously explained, the wheel turns about an axis at right angles to the axis of the applied force, *i. e., revolves* the vertical shaft as indicated in Figures 9(b) and 9(c). As this revolving movement also carries the vertical *plane* of the weight force, *along with it,* the wheel continues in its effort to bring its plane in coincidence with the plane of the weight. This leads to the vertical axis marked as P. This *precession* ceases as soon as the weight is removed. Reversal of the direction of spin, or, reversal of the end to which the weight is suspended, reverses the direction of the precessional motion.

Compound Forces Acting on a Gyro System.—Two or more forces acting upon a gyro system, may be analyzed on the basis of the mechanical *resultant* of the two forces and the applied rule of precession. In the previous experiment, in which precession is caused by a weight, if the precession is *assisted* by *pushing* the frame around in the same direction in which it was precessing, it is found that the weight *rises,* and this new motion continues until the weight reaches the uppermost point in the gyro system. The "assistance" given to the precession is actually a second force having its own precession in the *vertical* plane. Figure 10 shows the gyro wheel rotation in the plane of the paper. A major force, AB, downward, corresponding to the weight, on the end of the axle A nearer to the observer, causes right angle precession in the direction AC about the axis ZZ. A minor force AD in the direction of the precession, corresponding to the "assistance," causes the wheel to precess in the direction AF about the axis YY. The *resultant* force is represented by AE, both in direction and

magnitude, and the *resultant precession* is in the direction AP at *right angles* to AE and about the *resultant axis* GE. The direction of the *resultant precession* indicates that the weight rises by following a helical ascending track as the gyro frame rotates. Similarly, if the minor force AD is in a direction *opposed* to the precession, as in Figure 11, the direction of the resultant precession is downward, and the weight falls by following a helical descending track as the rotation of the frame continues.



FIGURES 10 and 11.—COMPOUND FORCE AE ACTING ON A GYROSCOPE CAUSES PRECESSION IN THE DIRECTION AP.

Suppression of Freedom About the Vertical Axis.—In the foregoing figures it will be obvious that if the two forces are equal, the resulting track of the precession will be at an angle of 45 degrees upward in Figure 10, and 45 degrees downward in Figure 11. If the force AD in Figure 11 is further increased, it will become the *major* force and the resultant precession AP will approach the vertical AZ. If it is increased to an amount *infinite* in comparison with AB, a condition obtained by *locking* the vertical axis of the gyroscope against rotation in the direction of the horizontal component, then the resultant precession AP coincides with AZ and the wheel then turns over about the horizontal axis YY *without resistance*. This effect is illustrated in Figure 12(a) which shows the gyro spinning with its axle horizontal, but with the vertical axis *locked* by the screw S. On hanging on the weight as shown in Figure 12(b), the frame immediately turns over as in Figure

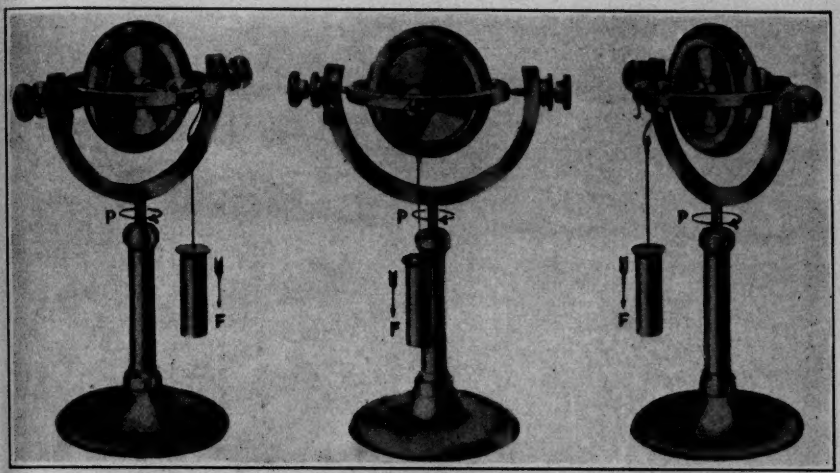


Fig. 9 (a). Fig. 9 (b). Fig. 9 (c).

FIGURES 9 (a), 9 (b) and 9 (c).—ILLUSTRATING CONTINUOUS PRECESSION CAUSED BY A WEIGHT WHICH REVOLVES WITH THE PRECESSION.

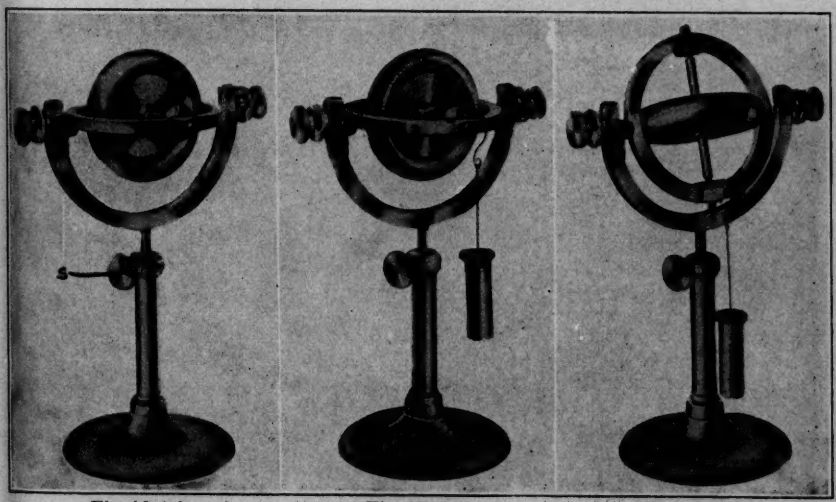


Fig. 12 (a). Fig. 12 (b). Fig. 12 (c).

FIGURES 12 (a), 12 (b) and 12 (c).—LOCKING THE VERTICAL AXIS AGAINST PRECESSION CAUSES APPLIED WEIGHT TO FALL FREELY.

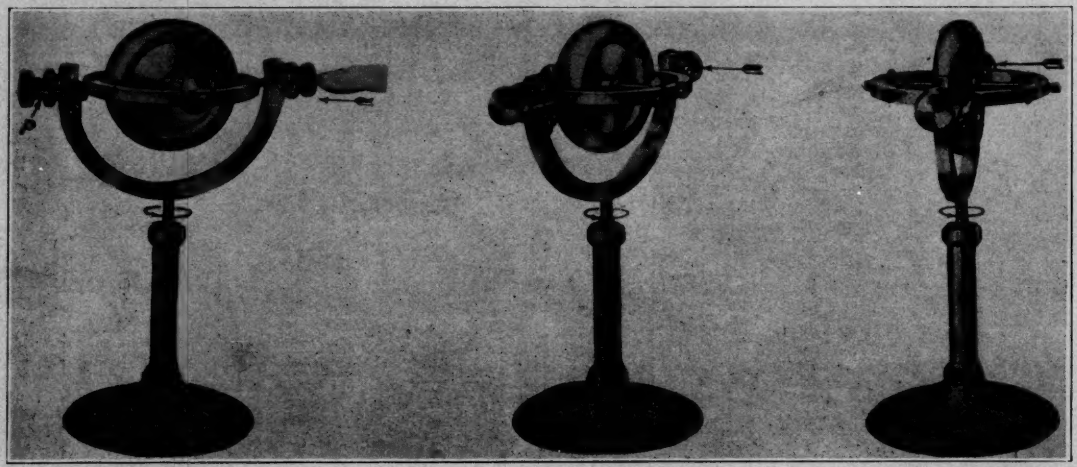


Fig. 13 (a). Fig. 13 (b). Fig. 13 (c).

FIGURES 13 (a), 13 (b) and 13 (c).—LOCKING THE HORIZONTAL AXIS AGAINST PRECESSION, PERMITS THE VERTICAL PLANE OF THE WHEEL TO ROTATE FREELY.

13(c) without resistance. The weight falls irrespective of the direction of spin.

Suppression of Freedom About the Horizontal Axis.—Similarly, in Figure 13(a), if the freedom about the horizontal axis is suppressed by the insertion of the pin P, the vertical axis being free, it will be found on pushing the frame around in either direction about the vertical axis as in 13(b) and 13(c), that there is *no resistance* to the motion. This is for the reason that the locking pin *suppressed* the *force* component AB, and also *suppressed* the *vertical precession* resulting from pushing the frame around.

APPLICATION OF PRINCIPLES TO THE SEA-GOING GYRO COMPASS.

Problems of the Gyro Compass.—In order to appreciate the design of the *gyro compass,* it is necessary to be acquainted with the problems involved. The basic problem, of course, is to have the compass indicate the *geographical meridian, i. e.,* the north and south line of the earth. This indication should be maintained regardless of any change in the location of the compass on the earth's surface. Also for sea-going application, the compass should have properties of *seeking* the meridian, or else, due to friction of mechanical supports, the compass would be *dragged* from the meridian on turning of the ship. Further, the speed of the ship and its direction, in conjunction with the earth's rotation, produce *resultant* directional forces which must be considered in the precessional efforts of the gyro wheel. In addition there are motions and forces produced by the roll, pitch and yaw of the ship which must be recognized and rendered harmless. Also there are accelerating and de-accelerating forces resulting from the change in the speed or course of the ship, the effect of which must be made use of in certain cases and eliminated in others.

We have seen, that when a gyroscope is placed on the equator with its axle parallel with the earth's axis, there are no forces tending to deflect it. We have seen, that a gyroscope *with three* planes of freedom with its axle not parallel with the earth's axis, will not of itself seek the meridian, but that the *rigidity* of the wheel in space causes *apparent* inclination or tilting of the wheel with respect to the earth's surface. We have seen, that the gravity

effect of hanging a weight on one end of the wheel axle, causes gyroscopic *precession* in accordance with definite gyroscopic laws. We shall now see, the further mechanical arrangements employed to first make the gyroscope into a *stationary* or *land* compass.

The Pendulous Gyro.—If a weight W is attached to the frame of the gyro wheel as in Figure 14(a), the system becomes pendulous, that is, gravity acting on the weight tends to restore and maintain the axle of the wheel horizontal. Again, placing the gyro wheel and its pendulous mounting on the earth's equator and having set the wheel spinning with its axle extending east and west (as in Figure 3, position O), we will find that both fundamental properties of the gyro wheel (rigidity and precession) are called into play. For, as the earth rotates, the axle becomes inclined to the horizontal (as in Figure 3, position 3), which, as in Figure 14(b), raises the weight W against the pull of gravity and consequently applies a turning force on the gyro wheel about horizontal axis B-B′. This force causes *precession* about the vertical axis C-C′ in the direction indicated in Figure 14(c) so that the gyro axle moves out of its E-W position toward a N-S position. This precession *continues,* the inclined axle crossing the meridian (Figure 14(d), and precessing past, under the energy stored in weight W, until it is again E-W and horizontal, as in Figure 14(f). At this point, as the arrow showing the direction of the wheel spin is reversed, the continuing inclination of the wheel axle caused by the earth's rotation, causes a reversed precession to immediately begin, accompanied by a return precession across the meridian back to the original E-W starting position.

The path of the end of the gyro axle is an attenuated (narrow) ellipse, as illustrated by the polar diagram, Figure 15, in which the original East-West deflection is represented as NA. Starting at the point A, the path of the axle precession in the horizontal plane and the tilting NC in the vertical plane caused by the earth's rotation, describes the ellipse BCDFA about the north point N. Since we have assumed frictionless support for the gyro wheel, a series of similar oscillations about the meridian will take place, and such a gyro wheel is said to exhibit a direction force or *tendency* to seek the meridian.

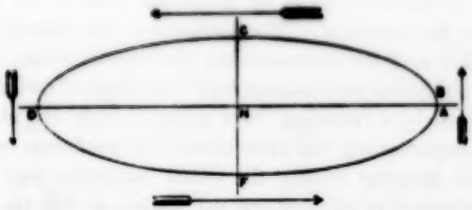


FIGURE 15.—CHARACTERISTIC PATH DESCRIBED BY THE AXLE OF A PENDULOUS EAST-WEST GYROSCOPE AS A RESULT OF TILTING AND PRECESSION.

Such a device, however, is of little practical value, as it would be necessary to observe it for at least one complete oscillation in order to determine the average or meridian position. Some means are therefore necessary to check or suppress the oscillations so that the end of the gyro axle will quickly come to rest in the N-S position. Introducing some slight amount of artificial friction about the precession axis C-C′ or the horizontal axis B-B′ would effectively check the oscillations, but it would also interfere with the accurate settling of the gyro axle in the meridian, since at small deflections the *directive* effort would be insufficient to overcome the friction employed.

Making the Gyro North-Seeking, the Arma Method.—If in some way the effect of the weight W could be reduced as the gyro axle approached the meridian, the next half-oscillation would be considerably less than the original deflection. The succeeding oscillations would then dampen out, without employing friction, until the gyro axle eventually came to rest on the meridian. A gyro with such an effect is said to be north-*seeking*. This effect is accomplished in one scheme by using devices known as damping tanks, consisting of a pair of vessels fixed to the N and S sides of the gyro frame (see Figure 16(a)). These vessels are partly filled with a suitable liquid such as oil (or kerosene), and are connected as shown by a small pipe which restricts the flow. This oil damping device starts to operate when the wheel axle begins a slow tilt due to the earth's rotation. During the precession toward the north caused by the weight W, the oil slowly flows with a regulated time lag, from one vessel to the other due to difference in elevation between them (see Figure 16(b)). The effect of the

weight W is then reduced in the horizontal plane as the gyro axle approaches the meridian. The oscillations are therefore partly suppressed in *both* the horizontal and the vertical planes in accordance with a physical phenomenon that " an elliptical oscillation may be suppressed by a retarding force acting in only *one* plane." By properly proportioning the gyro wheel, the pendulous weight W and the oil damping vessels, the initial oscillation may be completely suppressed in two and one-half cycles, so that the practical gyro wheel will finally come to rest in about three hours, with the oil vessels in balance, the wheel axle horizontal, and exactly on the meridian. With the gyro assumed to be *on the equator,* further rotation of the earth produces no tilt of the wheel axle and it becomes inert on the meridian until deflected by some external force. This method of damping operates about a *horizontal* axis in contrast with the following Sperry method which operates about a vertical axis.

Making the Gyro North-Seeking, the Sperry Method.—The foregoing shows the existence and the necessity of damping the natural oscillations of a pendulous gyro wheel when deflected from the meridian. The restricted oil scheme shown for its suppression is one of the basic methods of damping a gyro compass. Another *north-seeking* arrangement is known as the *mercury ballistic.* In this scheme there is no pendulous weight, but a pair of vessels attached to the N and S sides of the gyro frame, as in Figures 16(a) and 16(b), are partly filled with *mercury,* and are connected by a pipe of small bore which is practically *unrestricted.* When the wheel axle is caused by the earth's rotation to slowly tilt, the free-flowing mercury, seeking its level, builds up a force on the *low* side similar to but in the opposite direction to that produced by a pendulous weight, see Figures 17(a) and 17(b). This produces north-seeking properties the same as a pendulous weight, but since the force is applied to the *low* side of the gyro instead of on the *high* side, as is the case with a pendulous weight, the resulting *precession* is oposite, hence the direction of rotation of the gyro wheel must also be reversed so that the gyro will be turned toward the meridian by the action of gravity on the mercury. The resulting movement will be an elliptical oscillation as shown in Figure 15 and further means of damping are necessary.

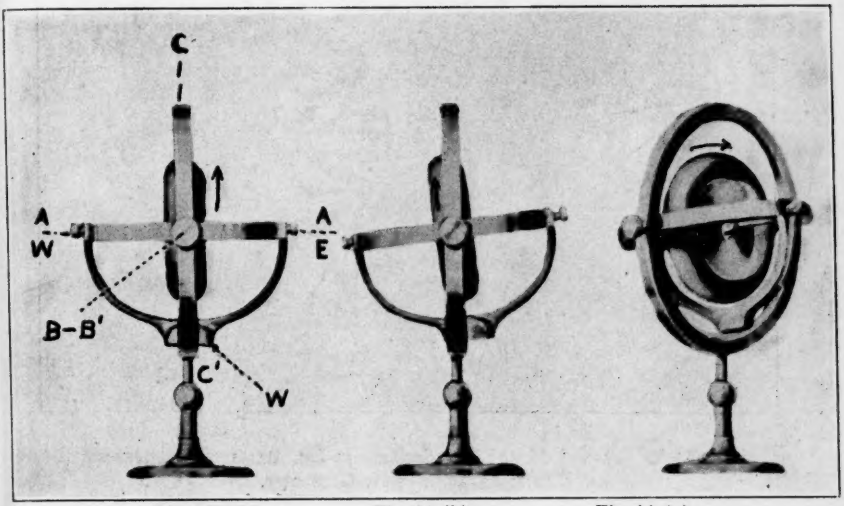


Fig. 14 (a). Fig. 14 (b). Fig. 14 (c).

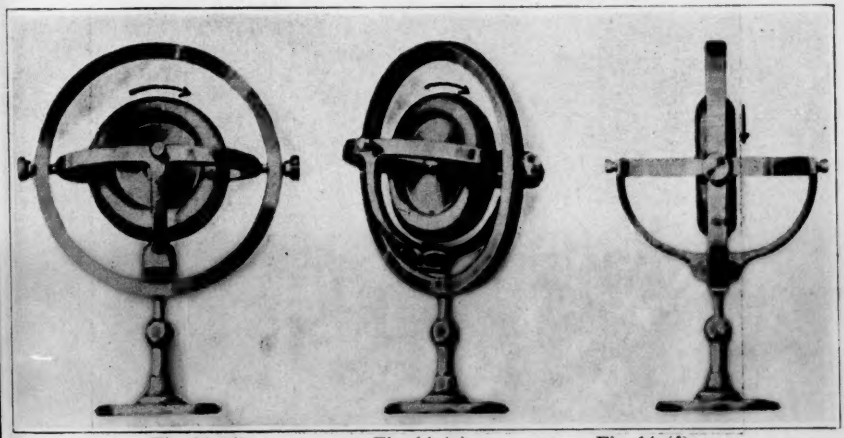


Fig. 14 (d). Fig. 14 (e). Fig. 14 (f).

FIGURES 14 (a), 14 (b), 14 (c), 14 (d), 14 (e) and 14 (f).—A PENDULOUS EAST-WEST GYROSCOPE ON THE EQUATOR, TILTING AND PRECESSING 180 DEGREES HORIZONTAL TURN-ABOUT.

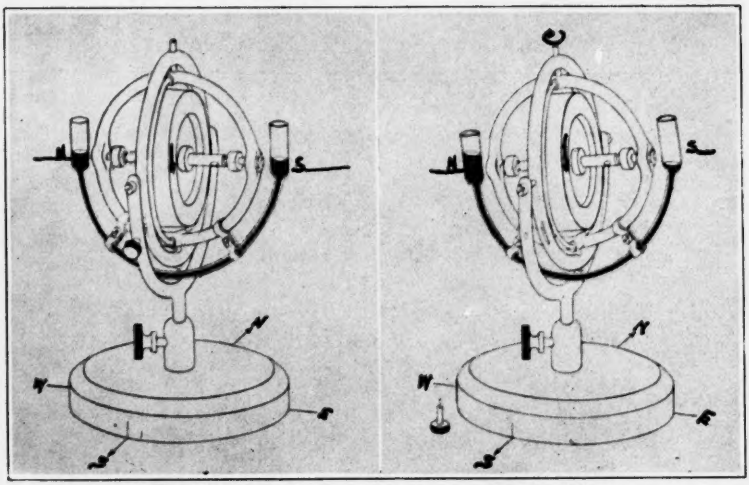


Fig. 16 (a). Fig. 16 (b).

FIGURES 16 (a) and 16 (b).—A SCHEMATIC OIL BALLISTIC DAMPENING DEVICE ATTACHED TO A GYROSCOPE.

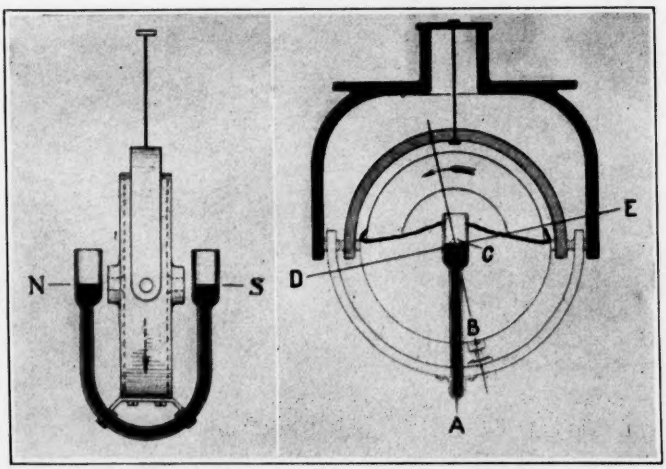


Fig. 18. Fig. 19.

FIGURE 18.—THE FUNDAMENTAL MERCURY BALLISTIC SO ATTACHED HAS NO DAMPENING PROPERTIES.

FIGURE 19.—THE MERCURY BALLISTIC HUNG FROM A PHANTOM SUPPORT, APPLIES DIMINISHING PRESSURE ON ECCENTRIC PIN B TO CAUSE COUNTER-PRECESSION, RESULTING IN DAMPENING.

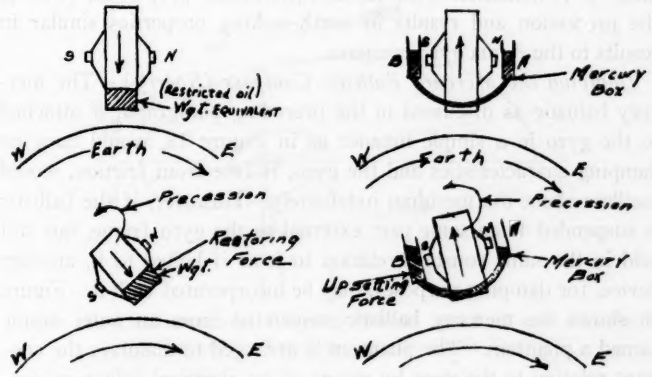


Fig. 17 (a). Fig. 17 (b).

FIGURES 17 (a) and 17 (b).—COMPARISON OF THE RESTRICTED OIL BALLISTIC AND THE MERCURY BALLISTIC, SHOWING THE DIRECTION OF WHEEL SPIN AND PRECESSION TO THE NORTH.

Contrast of the Arma and the Sperry Systems' North-Seeking Properties.—The foregoing shows the *contrast* between the north-seeking properties of the Arma system and that of the Sperry system. To make this clearer, in the Arma system the pendulous weight, in combination with a certain direction of rotation of the gyro wheel (same direction as the earth's rotation), causes precession to the north, which in turn is damped by the retarded or restricted oil from the damping tanks. In the Sperry system the tanks are not *damping* tanks, but the free-flowing mercury is used in combination with the *opposite* direction of rotation of the gyro wheel to obtain the gyroscopic force required to obtain precession to the north. The additional scheme for *damping* the Sperry compass will be described in the following paragraph. The Arma compass, therefore, is termed a *pendulous* compass and the liquid tanks are *damping* tanks. In the Sperry compass the liquid tanks are termed *mercury ballistics* and, when settled on the meridian with the mercury at level, the compass is non-pendulous. When off the meridian the tilt resulting from the earth's rotation causes the mercury to flow to the low side and the Sperry compass may then be said to be *anti-pendulous* or with opposite precessional effects to the Arma *pendulous* compass. The anti-direction of rotation (opposite to the earth's rotation) which the Sperry gyro wheel oper-

ates, in combination with its anti-pendulous properties, rectifies the precession and results in north-seeking properties similar in results to the Arma gyro compass.

Damping the Mercury Ballistic Compass (Sperry).—The mercury ballistic as discussed in the preceding paragraph, if attached to the gyro in a simple manner as in Figure 18, would have no damping characteristics and the gyro, if free from friction, would oscillate about the meridian indefinitely. However, if the ballistic is suspended from some part external to the gyro frame, but still held in the same constant relation to it as if bolted to it, another device, for damping purposes, may be incorporated with it. Figure 19 shows the mercury ballistic suspended from an outer frame named a phantom. The phantom is arranged to maintain the constant relation to the gyro by means of an electrical follow-up system which causes it to rotate and follow the precessions of the gyro axle. The connection between the phantom containing the mercury ballistic and the gyro frame, as shown in Figure 19, may be made by means of a pin exactly in line with the gyro (as at A, Figure 19), in which case the axle tilt will cause a pressure against the pin which in turn tilts the mercury ballistic on the phantom.

In the above arrangement, *precession* is accomplished, but it is *undamped,* in effect similar to Figure 18. However, if the point of contact of the pin is shifted eccentrically (as at B, Figure 19), the pressure on the pin will be in a direction and amount depending on direction and amount of the eccentricity of the pin. The eccentricity is adjustable, and the direction and amount of the force coupled at this point is regulated to apply a *reversed* or *opposed* inclined precession which results in a damping characteristic, as shown in Figure 20. The action of the (1) phantom, (2) the follow-up system and (3) the eccentric pin, is analagous to (1) an observer (2) moving around the compass in step with its deflections and (3) lightly touching it at the proper point to cause an opposed but gradually decreasing precessional tendency. This method of damping, using the phantom as the background, is termed *external* damping in contrast to the Arma oil damping method, which is entirely *internal.* It should be noted that the Sperry damping method above described, operates about a *vertical* axis.

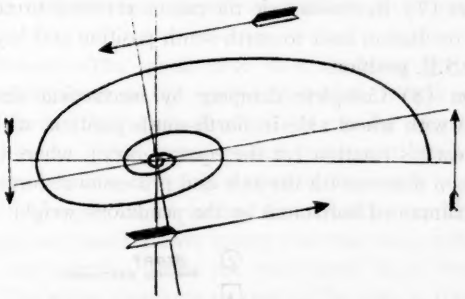


FIGURE 20—CHARACTERISTIC PATH OF WHEEL AXLE WHEN DAMPED BY THE ECCENTRIC PIN-MERCURY BALLISTIC DEVICE.

Summarizing the Fundamentals of a North-Seeking, Gyro Compass.—As outlined in the foregoing paragraphs, the successive fundamental steps of a north-seeking gyro compass are illustrated in Figure 21, which shows a gyro wheel *on the earth's equator.* The evolution of the wheel axle positions relative to the meridian, are the simplest to illustrate when located on the equator, and the various evolutions shown are explained for a *simple pendulous* compass with a damping device, as follows:

Position* (1) The spinning wheel axle is assumed to be pointing east-west.

Position (2) *Gyroscopic Rigidity* phenomenon holds position No. 1 in space and eventually the axle assuming a tilt relative to the earth's surface.

Position (3) *Gravity,* acting on pendulous weight W, brings wheel axle parallel to earth's surface.

Position (4) *Gyroscopic Precession* at right angles results from gravity component on the pendulous weight, changing the plane of the wheel.

Position (5) Wheel arrives in plane of earth's rotation, with axle pointing north-south, but with the north end *tilted.* The energy stored in lifting weight W continues the precessional oscillation beyond the north-south position.

Position (6) Limit of partly suppressed oscillation is reached, axle pointing N.E.-S.W.

* Three-hour intervals are indicated between evolutions in Figure 21, for illustrative purpose only. The actual time for the complete evolution from position 1 to position 8, varies from 2 to 4 hours, depending on the design of the gyro compass.

Position (7) Reversed axle tilt causes reversed precession with resulting oscillation back to north-south position and beyond to the N.S.E.-S.S.E. position.

Position (8) Complete damping by mechanical devices stops oscillation with wheel axle in north-south position, with wheel in plane of earth's rotation (at the equator only), where the rigidity phenomenon does not tilt the axle and precessional forces are zero. Axle is maintained horizontal by the pendulous weight.

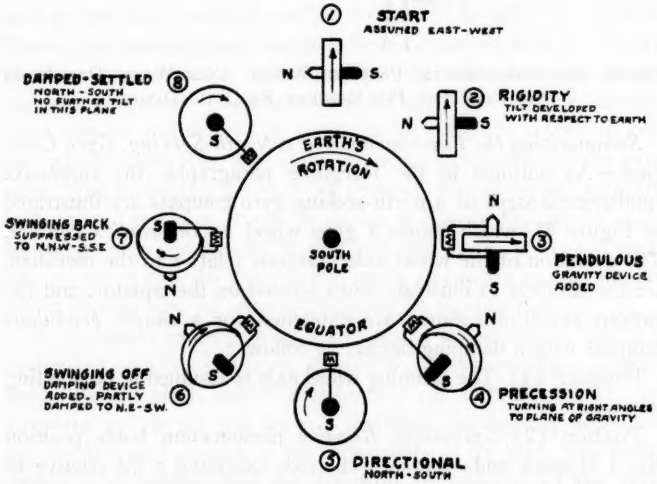


FIGURE 21.—SUMMARIZING THE PROGRESSIVE FUNDAMENTALS OF A NORTH SEEKING GYRO-COMPASS.

Characteristics of a Pendulous Gyro on a Ship.—It will now be seen that there has been produced a device capable of indicating true north, whose oscillations die out within a reasonable time; in other words, a satisfactory *land* compass. When used on *moving ships,* however, such a compass would be subjected to serious errors. The errors to which a sea-going gyro compass are subjected on the basis of fundamental effects caused by the movement or position of the ship are: (1) Speed and Latitude Errors; (2) Roll Errors; (3) Turning Errors; and (4) Latitude Error. These will be discussed in turn in the following paragraphs. In addition,

an artificial control effect known as *ballistic deflection* will be discussed.

Speed Errors.—The speed error of a sea-going gyro compass is one which arises from the *combination* of the ship's speed with that of the earth. So long as the ship is at rest the compass is controlled only by the earth's rotation, and consequently indicates true north. However, when the ship is moving due north or south this movement is at right angles to that of the earth (see Figure 22), and although very much slower except near the poles, it is sufficient to deflect the compass from the true north by a recognizable amount. This error decreases to zero as the ship is turned to an east or west heading, in which directions the plane of the ship movement *coincides* with the plane of the earth's rotation and merely adds to or subtracts from the basic force.

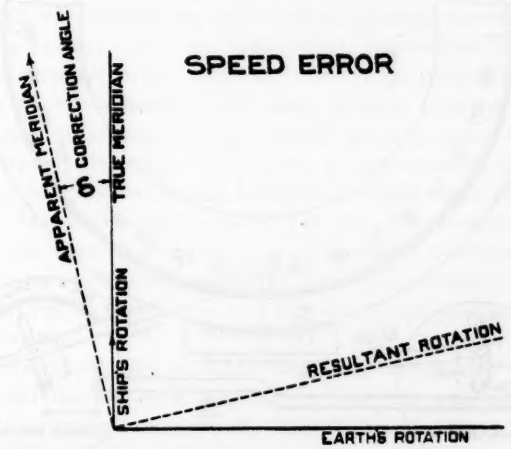


FIGURE 22.—ILLUSTRATING THE EFFECT OF A SHIP SPEEDING ON A NORTH COURSE. THE APPARENT MERIDIAN IS AT RIGHT ANGLES TO THE RESULTANT COMPONENT OF THE SHIP'S AND THE EARTH'S ROTATION.

Speed and Latitude Errors.—The earth's speed of rotation (approximately 900 nautical miles per hour at the equator) gradually decreases as the latitude increases, so that at the poles its surface speed of rotation is zero. A given ship's speed in the north-south direction will therefore have an increased effect at higher latitudes

and the compass would *ultimately* be 90 degrees in error at the poles. The *practical* limit of reliable compass operation is around 70 degrees (north or south) latitude, this being the limit of the corrective devices employed. From the foregoing, the total speed error, therefore, depends on (1) Ship's speed; (2) Ship's course, and (3) Latitude. These errors are definite, pre-determined, and are corrected by a mechanical device such as shown in Figure 23. This device serves to *shift* the *lubber line* (line of the ship's head) of the *transmitter* on the compass so that the repeater compasses read *true* north, while the master compass wheel axle remains on the *virtual* meridian. The *virtual* meridian is defined as the *resultant* or *apparent* north, obtained from the force combination of the ship's speed and the earth's rotation when this resultant is not parallel to the plane of the axis of the earth's rotation.

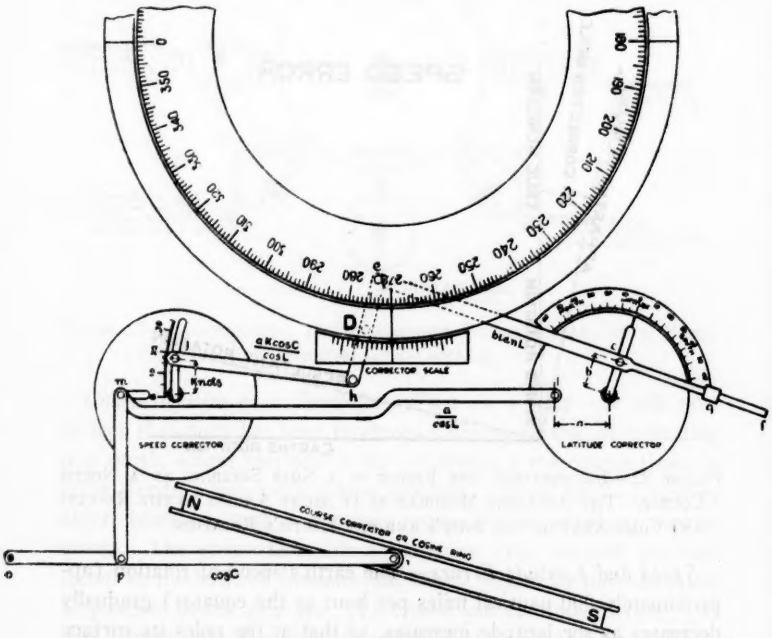


FIGURE 23.—A TYPICAL MECHANICAL CORRECTION DEVICE FOR SHIFTING THE LUBBER LINE TO COMPENSATE FOR PRE-DETERMINED ERRORS CAUSED BY SHIP'S SPEED, SHIP'S COURSE AND LATITUDE.

Roll Error.—This error is caused by an accelerating force, the resultant of the movement of the ship as it rolls from port to starboard. Rolling in an east-west plane has no effect on the compass, as this movement, when the axle is on the meridian, is in the plane of the rotation of the wheel, and therefore exerts no action on it (see Figure 24). Rolling in the *north-south* plane also has no effect, as the period of the compass is so long that the effect of rolling in one direction is cancelled by a roll in the opposite direction before any deviation of the compass can be apparent (see Figure 25). However, in the inter-cardinal planes (N.E.-S.W. and N.W.-S.E.) the roll errors do not cancel. For this reason roll errors are sometimes called *inter-cardinal* errors. In the earlier types of gyro compasses no provisions were made for their suppression, as the theory of their existence has not yet been advanced. It is natural to assume that if no east-west or north-south roll errors exist, that roll errors in the inter-cardinal direction should be likewise non-existent. On the fundamental single-wheel pendulous compass these errors are sufficient to deflect the compass 20 to 40 degrees off the meridian. The cause is quite involved and the explanation of its origin will be omitted, except to state (referring to Figure 26) that on a N.W. course a west deviation developes and on a N.E. course an east deviation developes under conditions of roll. It is in evidence, however, only when the sensitive element of the gyro is not stabilized or is unsymmetrical as a swinging mass. Roll errors, which include pitch errors, are not calculated or compensated, but are suppressed or reduced to a negligible amount by several methods.

The Sperry Method of Suppressing Roll Errors.—It has been stated that the roll error originates in common with an unsymmetrical swinging mass. In the latest form of Sperry compass the sensitive element, including the mercury ballistic, is designed to be entirely symmetrical, *i. e.,* balanced *above* and *below* the horizontal axis, so that the roll or pitch of the ship does not build up an accelerating force in any plane which will cause precession of the wheel. This balance is accomplished to exactness by the use of adjustable compensating weights. The mercury ballistic not only lends itself to the control of the precessional force, but, when *settled,* it is normally symmetrical about the horizontal axis in con-

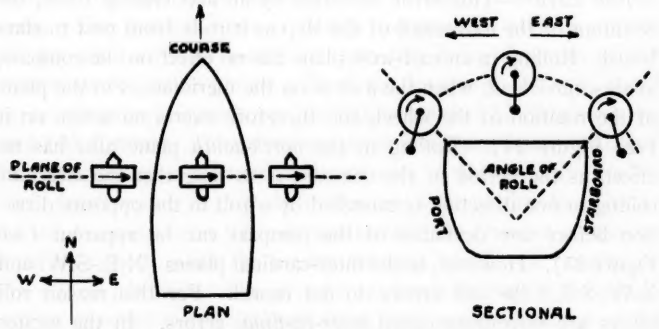


FIGURE 24.—EAST-WEST ROLL ON A NORTH COURSE IN THE PLANE OF THE WHEEL, SHOWING NO ROLL PRECESSION.

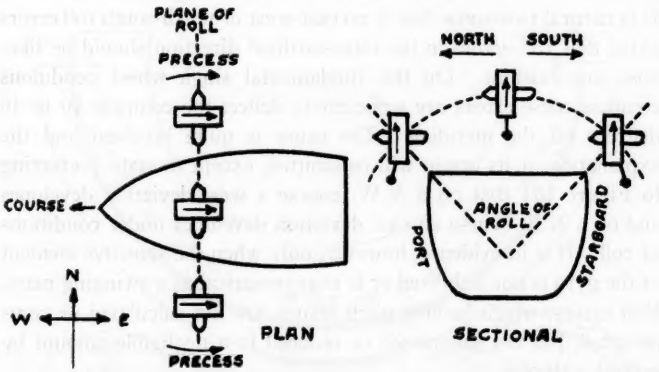


FIGURE 25—NORTH-SOUTH ROLL ON A WEST COURSE, SHOWING PORT ROLL PRECESSION CANCELS STARBOARD ROLL PRECESSION.

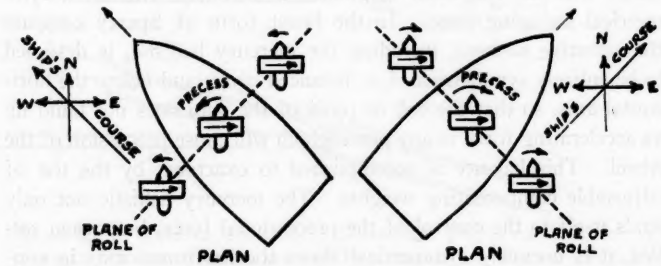


FIGURE 26—INTERCARDINAL ROLL OR INTERCARDINAL COURSES CAUSE PRECESSION IN THE DIRECTION OF THE SHIP'S COURSE.

trast to the *pendulous* compass. It is therefore practically immune to rolling forces. Any remaining tendency to roll errors is reduced by virtue of the fact that the transfer of the mercury through the small equalizing tubes of appreciable length is necessarily *out of phase* with the relatively fast roll-acceleration forces. It is to be noted that the flow of mercury, while acting relatively slow under roll forces, is regarded as being practically unrestricted as a *ballistic,* previously described under the north-seeking properties of the Sperry mercury ballistic compass.

The Arma Method of Suppressing Roll Errors.—In the Arma system two or three gyro wheels revolving at the same speed are used in combination to effect stabilization, so that roll errors are suppressed by this means, in contrast with the Sperry method of using one wheel and symmetrical arrangement of the elements. In order to make the action of the *two-wheel* gyro clear it is first assumed that the wheels are set with their axles parallel, as in Figure 27. Comparing this arrangement with a single-wheel gyro, it has simply increased the directive effort to twice its former value, but it still is affected in the intercardinal headings by roll accelerations. If now the two wheels are turned at right angles and held in position by centering springs, as in Figure 28, the effect is to oppose or neutralize any east-west swing tendency, but the north-south stability is lost as well as the directive effort. An intermediate position, however, between the extremes of Figures 27 and 28, as in Figure 29, affords a condition where the compass has directive force and also stabilization in both north-south and east-west directions. From the above, the only purpose of using two or three gyros is to prevent east-west swinging of the compass, which is the basic cause of the intercardinal errors encountered, and that the meridian-seeking action of the two or three wheel compass is identical in every way with that of a pendulous single wheel compass.

Turning Error.—This error arises from the effect of a change in velocity of the ship upon the *oil damping system* of the Arma compass, and upon the mercury *ballistic* of the Sperry compass. Considering a compass mounted on a ship traveling north at 20-knot speed, if the ship quickly executes a 180-degree

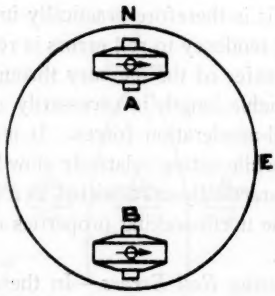


Fig. 27.

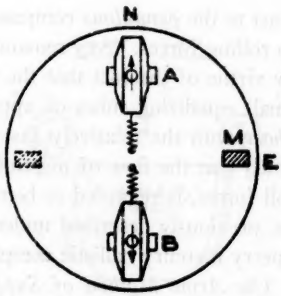


Fig. 28.

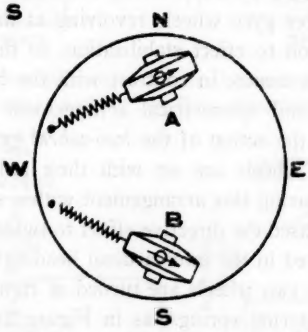


Fig. 29.

FIGURES 27, 28 and 29—ILLUSTRATING THE VARIOUS BASIC RELATION OF A TWO-WHEEL GYRO-COMPASS. FIGURE 29 ILLUSTRATES THE RELATION WHICH COMPENSATES FOR ROLL ERRORS IN EVERY PLANE.

turn, the compass undergoes a change of velocity in the north-south direction of 40 knots. The *liquid* in the north-south Arma *damping* tank and in the Sperry *ballistic* are subjected to the accelerating force and normally results in a small quantity of liquid being transferred, with resulting precessional deflection of the compass from the meridian. This error continues as a small oscillation until damped out by the action of the damping devices.

Suppressing the Turning Error.—In the Sperry compass, this is accomplished electrically by shifting the *eccentric pin* to the neutral axis which temporarily suspends the action of the damping device until the turning movement of the ship is completed. In the Arma compass, the turning error is suppressed by the application of an electric valve which automatically shuts off the connection

between the north and south oil tanks whenever the turning angle is large enough to operate the mechanism of the valve control.

Latitude Error.—The *Sperry* compass has a local latitude error due to a small inherent tilt with consequent deflection caused by the mechanical or eccentric pin means of damping the compass about the vertical axis. This error, which varies with the latitude, is predetermined and is corrected by operating a graduated dial which shifts the lubber line of the master compass. In the *Arma* compass, there is no local latitude error, for the reason that the damping system operates about the *horizontal* axis and causes no inherent *tilt* of the sensitive element.

Ballistic Deflection.—Ballistic deflection in a gyro compass is the ability to automatically precess the compass through an arc of predetermined value in a predetermined time in order to maintain the speed latitude correction during and after a turn or change in course is made. For example, a gyro compass has a speed error of 1.3 degrees east, at 20 knots due north. After a turn is made to due south at 20 knots, the speed error would normally be 1.3 degrees west. In order to maintain the correct heading during the turn and at the completion of the turn, the sensitive element must be precessed in a dead-beat manner a total of 2.6 degrees.

In the Sperry compass this is accomplished by the designed area and leverage of the mercury ballistic boxes, the effect of which is manually adjustable for *latitude* by increasing or decreasing their pendulous effective distance from the center of the rotor. The speed factor of the turn of the ship is taken care of automatically by virtue of the increase or decrease in the amount of mercury transfer dictated by the turn acceleration forces.

In the Arma compass, the *ballistic deflection* operates by also changing the pendulous effect of the sensitive element which in this compass is normally a fixed factor when the rotor speed is normal. This is accomplished by manually adjusting the *speed* of the rotors for the various latitudes by varying the frequency of the three-phase alternating current supplied to the induction motors in the sensitive element. When the ship turns, the regulated pendulous effect acts about the horizontal axis and causes precession about the vertical axis of a predetermined amount.

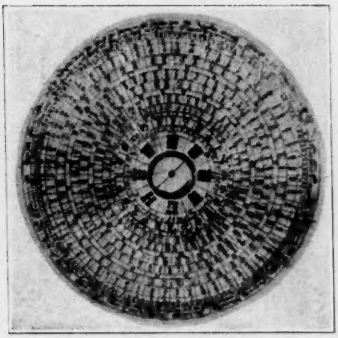
THE MECHANISM OF THE MODERN GYRO COMPASS.

Gyro compasses as used in the U. S. Naval service at the present day are confined to two distinct types, one as designed and manufactured by the Sperry Gyroscope Company and the other by the Arma Engineering Company. Both types use the same basic gyroscopic principles, but differ greatly in the mechanical methods of accomplishing the results. In general, the chief distinction between the two types is (*a*) the method of suspending the sensitive element; (*b*) the number of gyroscopic wheels employed; (*c*) the method of damping, and (*d*) the method of compensation for the movements of the ship.

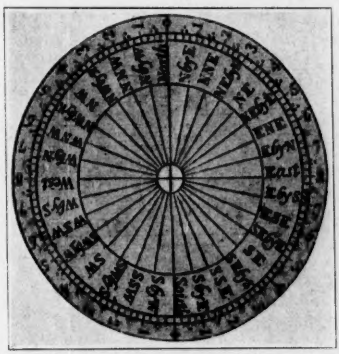
The Sperry Gyro Compass.—The latest type of Sperry gyro compass employs *one* gyroscopic rotor or wheel, weighing 75 pounds, revolving at 11,000 R.P.M., in a case and in a vacuum to reduce windage losses. The rotor and case constitute a duplex three-phase induction motor, the rotor being the secondary or squirrel cage element fitted to the interior rim of the rotor with the case containing the stator or primary windings (see Plate D). The rotor with its shaft, bearings, motor windings, and case, together with the compensator weights, vertical ring, follow-up armature, and the suspension, is termed the sensitive element (see Plate E), and is suspended from the phantom by means of a stranded torqueless steel suspension. The phantom element (see Plate F) consists of a hollow cylindrical stem, a ring, bearings which support the mercury ballistic, follow-up transformer, motor slip rings and the gears for driving the self-synchronous induction transmitters, which are used to reproduce the master compass readings to various parts of the ship by use of repeating instruments designated as *repeater compasses.*

The mercury ballistic is supported by the phantom element and consists of the parts which are designated in Plate G. The phantom (see Plate H) supports the vertical ring by means of the suspension and is in turn supported by bearings in the spider. In addition, the spider has mounted on it (see Plate I), transmitters, automatic damping eliminator switch, speed and latitude corrector and an azimuth motor. The spider with the above mentioned parts completely assembled on it, supports the sensitive element, phantom element and mercury ballistic. The spider itself is sup-

Earliest Known Professed Picture of a Compass in Any Printed Book—1521.



A Chinese Magnetic Compass.



The Navigator's Guide of the Seventeenth Century.

Modern U. S. Navy Magnetic Compass.

PLATE A.—MEDIEVAL AND MODERN MAGNETIC COMPASSES.

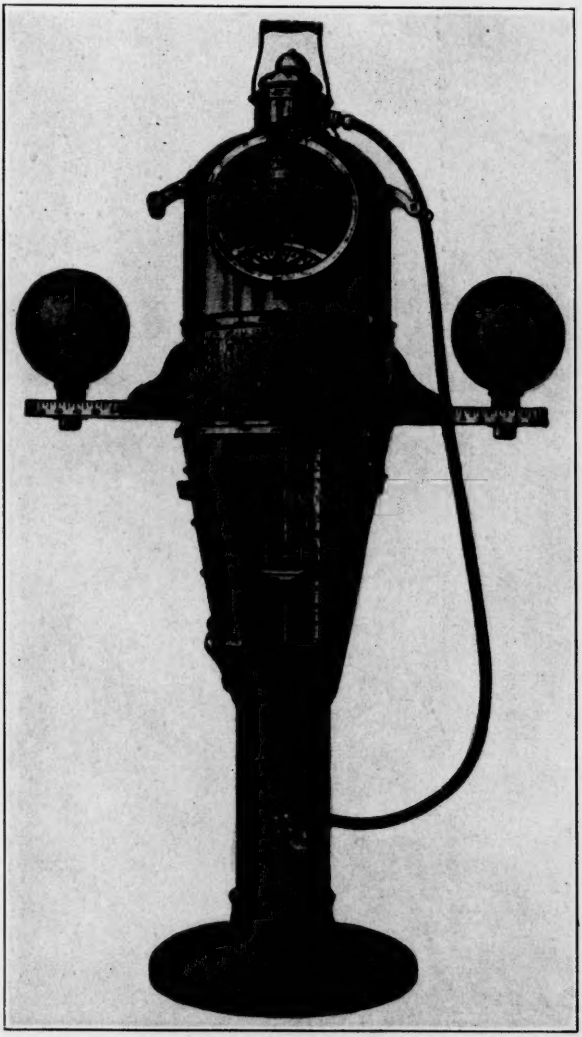


PLATE B.—U. S. NAVY COMPENSATED MAGNETIC COMPASS.

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GREENLAND

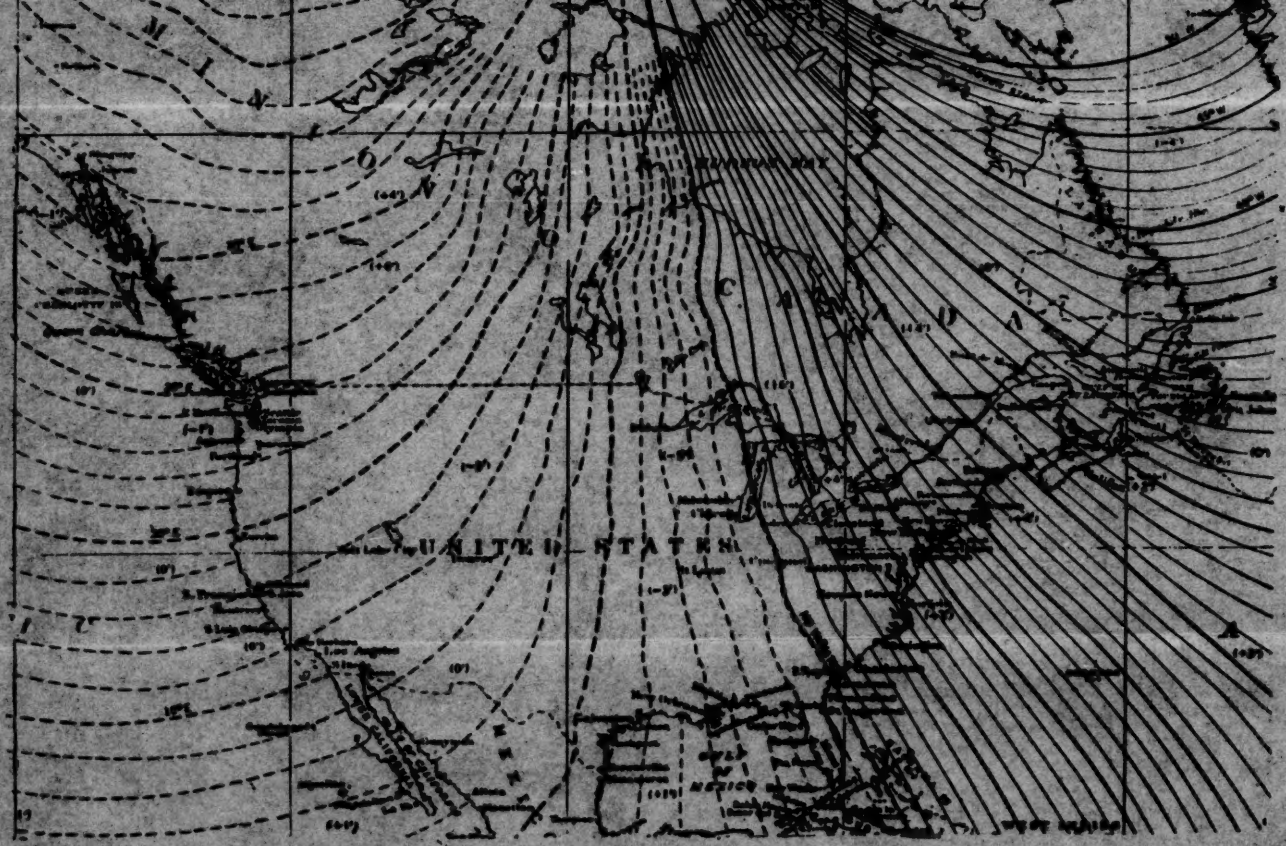


PLATE C.—SECTION OF 1930 MAGNETIC VARIATION CHART.

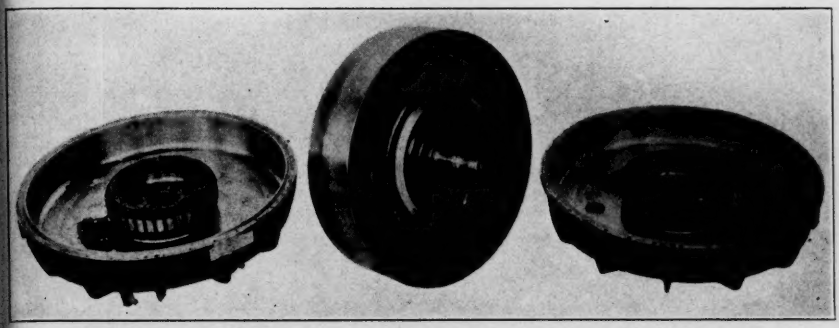


PLATE D.—THE SPERRY COMPASS, SHOWING THE INDUCTION MOTOR DUPLEX STATOR WINDINGS, AND GYRO WHEEL EXPOSING ONE OF THE DUPLEX SQUIRREL-CAGES OF THE ROTOR.

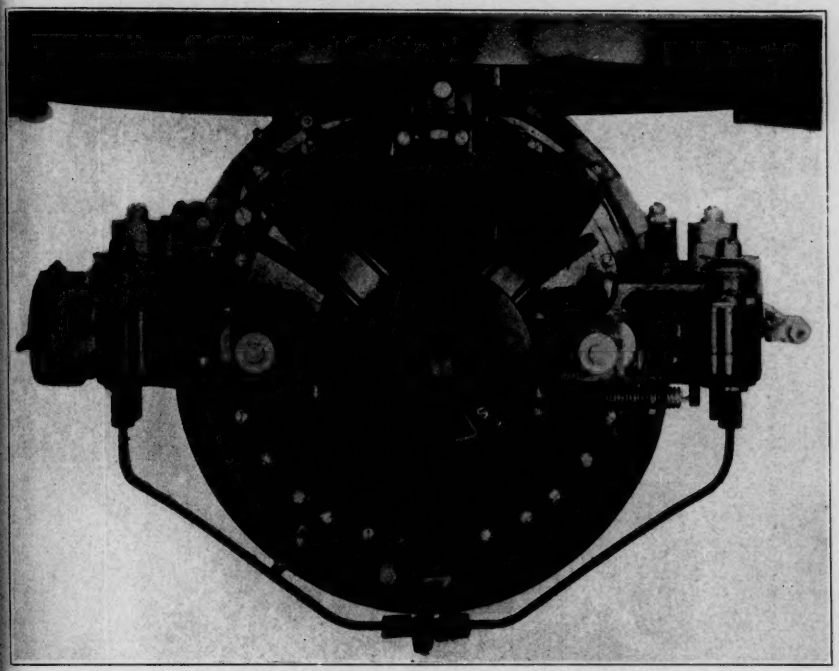


PLATE E.—THE SPERRY COMPASS, SHOWING THE SENSITIVE ELEMENT INCLUDING THE ROTOR BEARINGS, ROTOR CASE, COMPENSATOR WEIGHTS AND VERTICAL RING. THE MERCURY BALLISTIC, EQUALIZING TUBES AND PHANTOM RING ARE ALSO SHOWN.

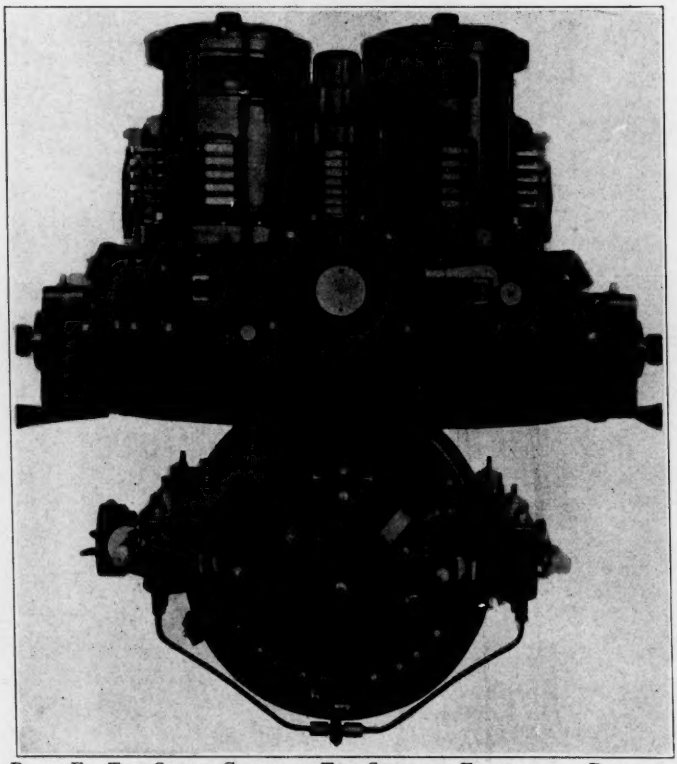


PLATE F.—THE SPERRY COMPASS. THE SENSITIVE ELEMENT AND BALLISTIC ATTACHED TO THE PHANTOM ELEMENT CONSISTING OF A HOLLOW STEM, A RING, FOLLOW-UP MECHANISM, MOTOR SLIP RINGS AND GEARS FOR DRIVING THE SELF-SYNCHRONOUS TRANSMITTER.

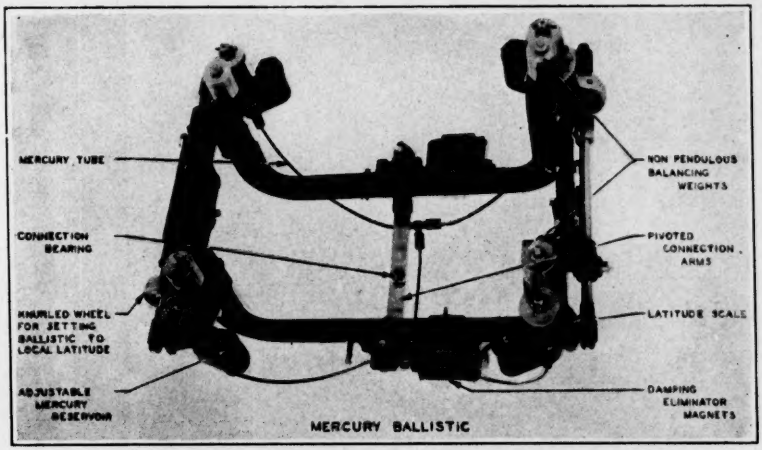


PLATE G.—THE SPERRY COMPASS. THE MERCURY BALLISTIC ASSEMBLY SHOWING THE CONNECTING TUBES, ADJUSTABLE RESERVOIRS AND DAMPING ELIMINATOR.

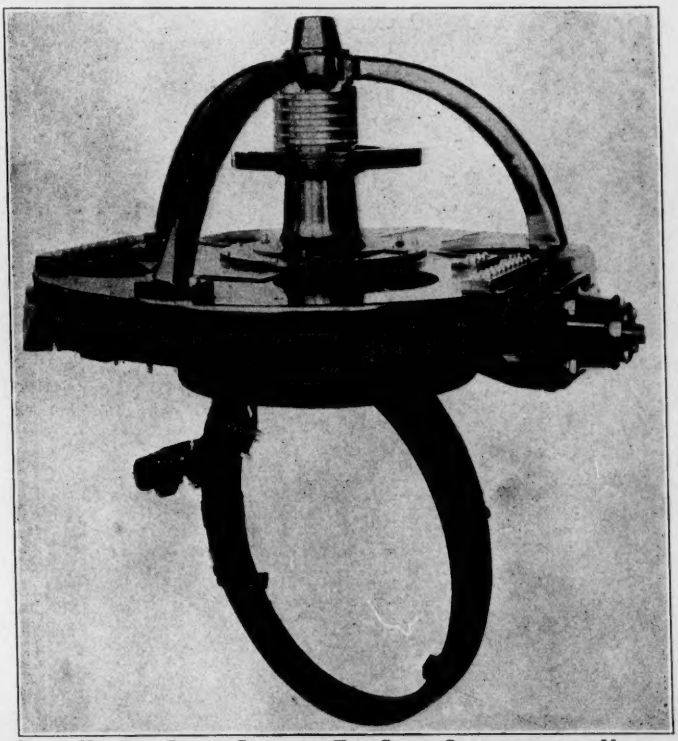


PLATE H.—THE SPERRY COMPASS. THE SPIDER SUPPORT FOR THE VERTICAL RING.

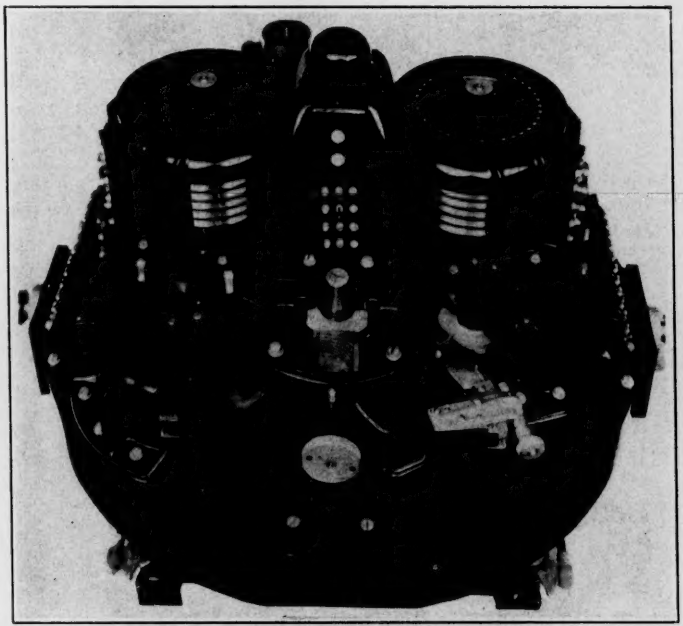
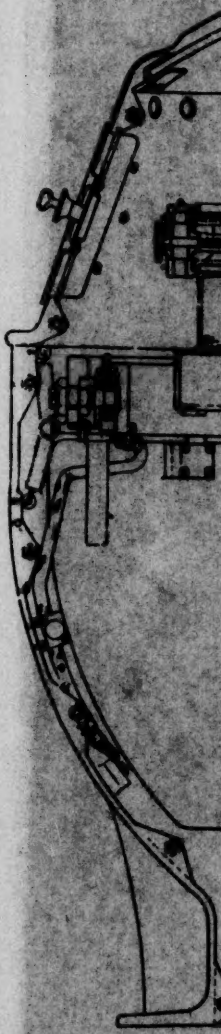


PLATE I.—THE SPERRY COMPASS. THE UPPER CONTROL ASSEMBLY CONSISTING OF TRANSMITTERS, SPEED AND LATITUDE CORRECTORS, AND AZIMUTH MOTOR.



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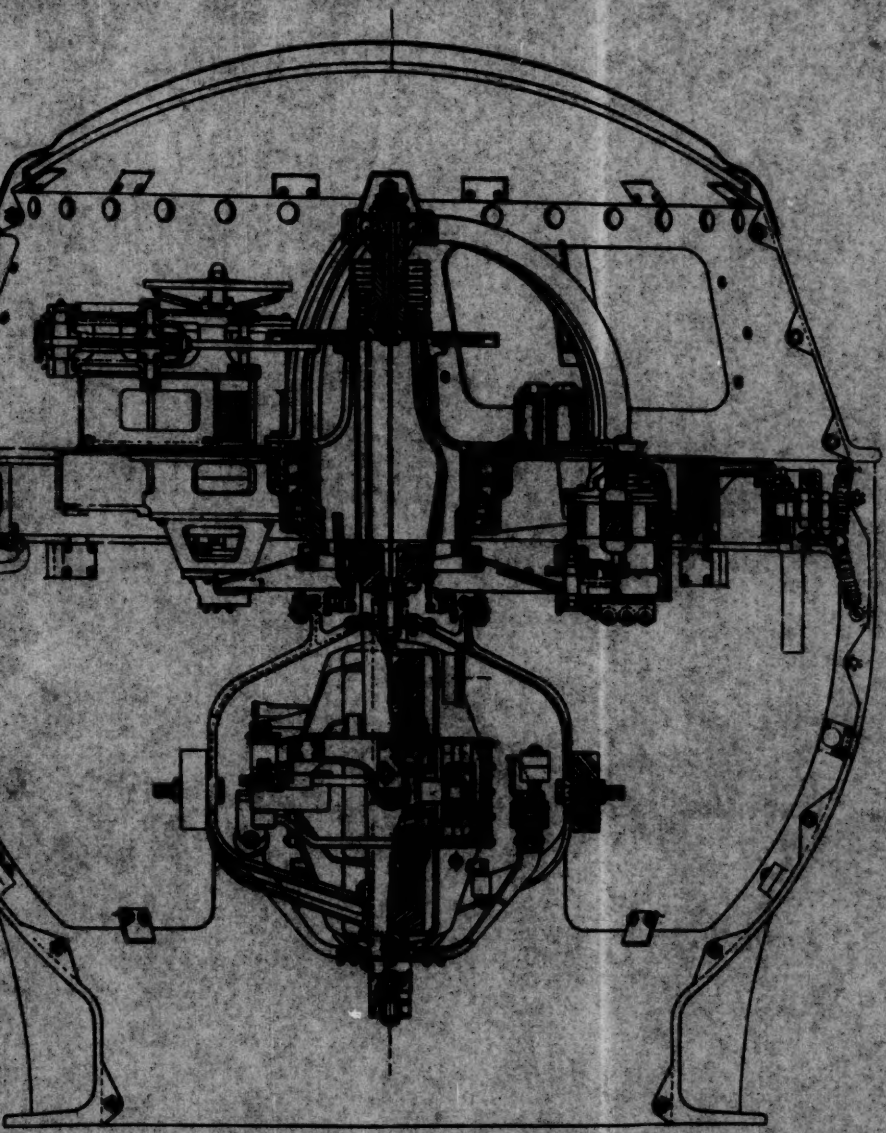

PLATE K.—THE SPERRY COMPASS. AN EAST ELEVATION OF THE COMPLETE MARK X MOD. 1, COMPASS IN ITS BINNACLE. TOTAL HEIGHT 53 INCHES, OUTSIDE DIAMETER 51 INCHES, WEIGHT COMPLETE 1358 LBS.

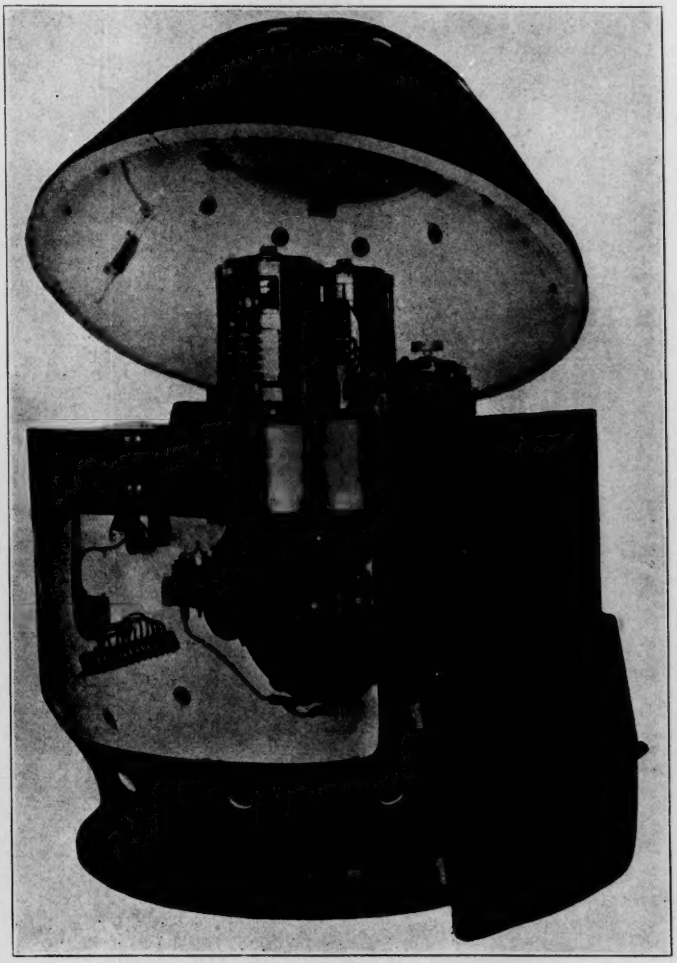

PLATE J.—THE SPERRY COMPASS. THE COMPLETE ASSEMBLED COMPASS SUSPENDED IN AN ENCLOSING CASE OR BINNACLE.

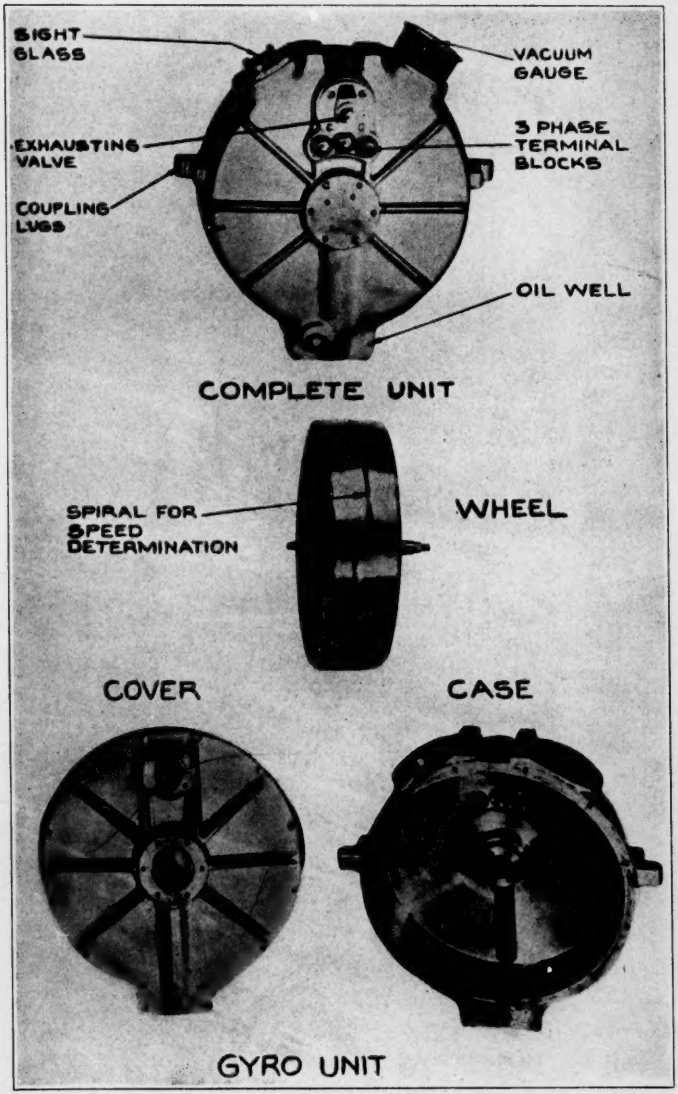

PLATE L.—THE ARMA COMPASS. SHOWING AN ASSEMBLED AND DISASSEMBLED VIEW OF ONE OF THE GYRO UNIT INDUCTION MOTOR GYRO WHEELS.

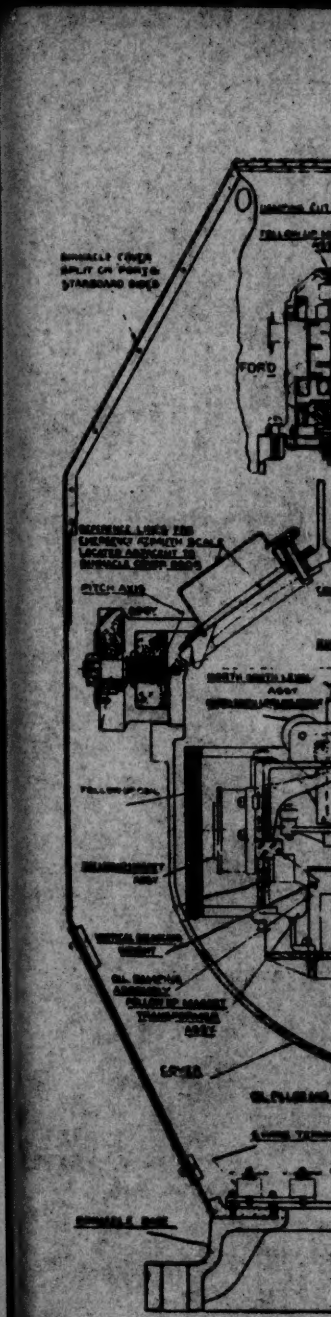

PLATE N
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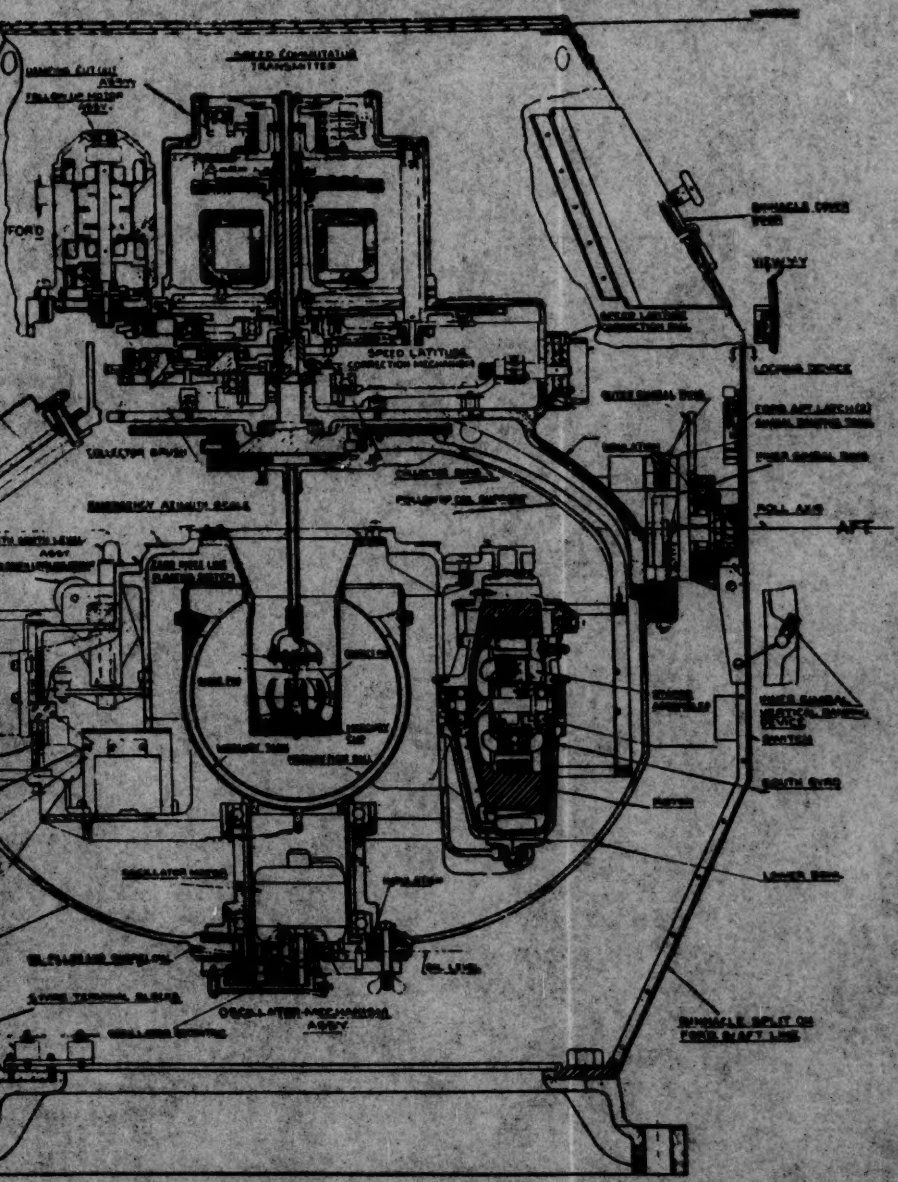


PLATE N.—THE ARMA COMPASS. A SIDE ELEVATION OF THE COMPLETE MARK VI MODEL 0 COMPASS IN ITS BINNACLE. TOTAL HEIGHT 45 INCHES, OUTSIDE DIAMETER 36 INCHES, WEIGHT COMPLETE 780 LBS.

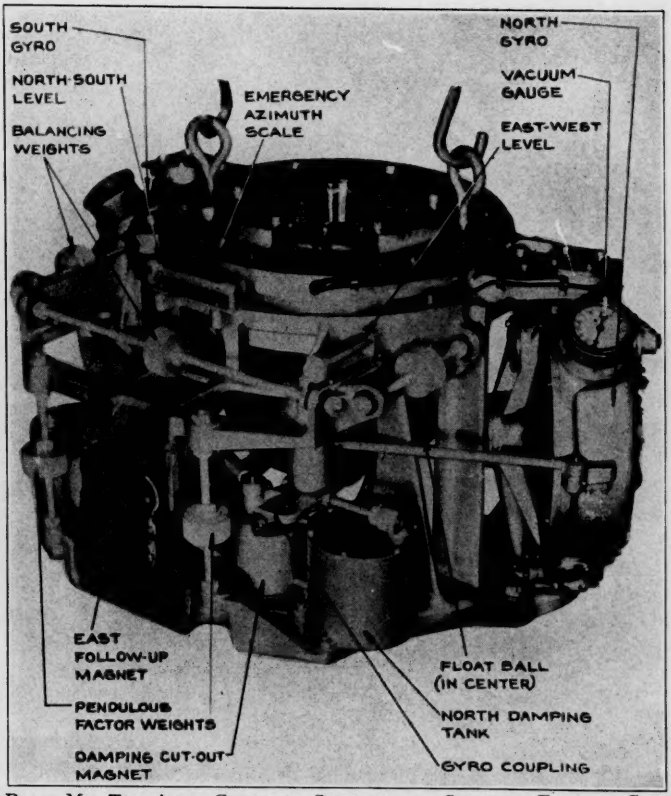


PLATE M.—THE ARMA COMPASS. SHOWING THE SENSITIVE ELEMENT CONTAINING THE GYRO WHEELS, OIL-DAMPENING SYSTEM, ADJUSTING WEIGHT AND BALL FLOAT WHICH SUPPORTS THE ENTIRE SENSITIVE ELEMENT.

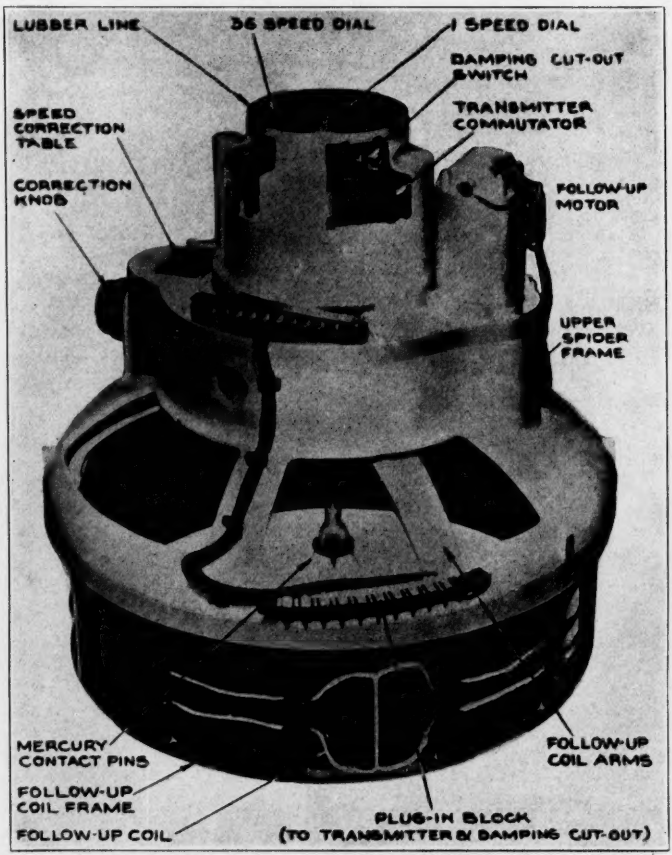


PLATE O—THE ARMA COMPASS. SHOWING THE UPPER SPIDER ASSEMBLY CONTAINING THE FOLLOW-UP MOTOR, SPEED MECHANISM AND SELF-SYNCHRONOUS TRANSMITTER.

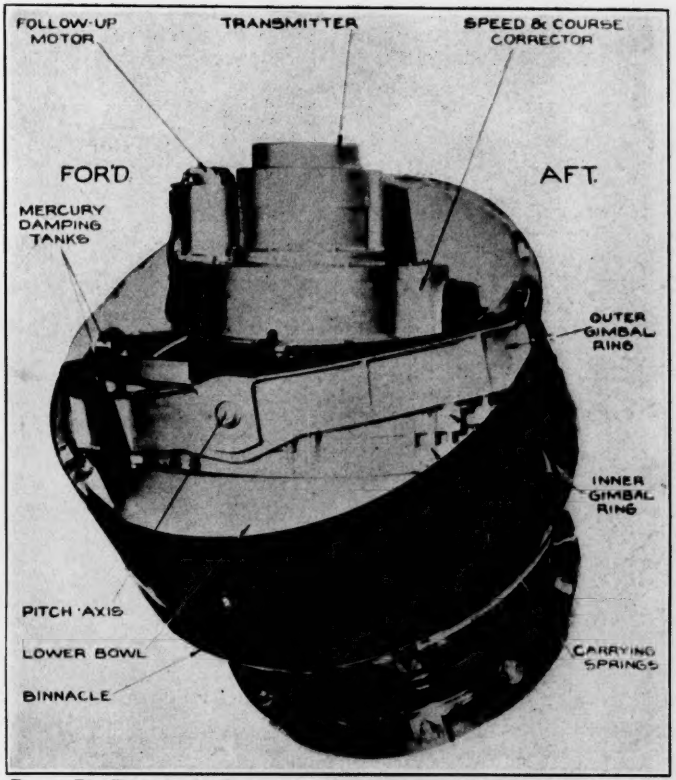


PLATE P.—THE ARMA COMPASS. THE ASSEMBLED COMPASS WITH COVER REMOVED, SHOWING POSITION FOR 40 DEGREE ROLL AND 10 DEGREE PITCH.

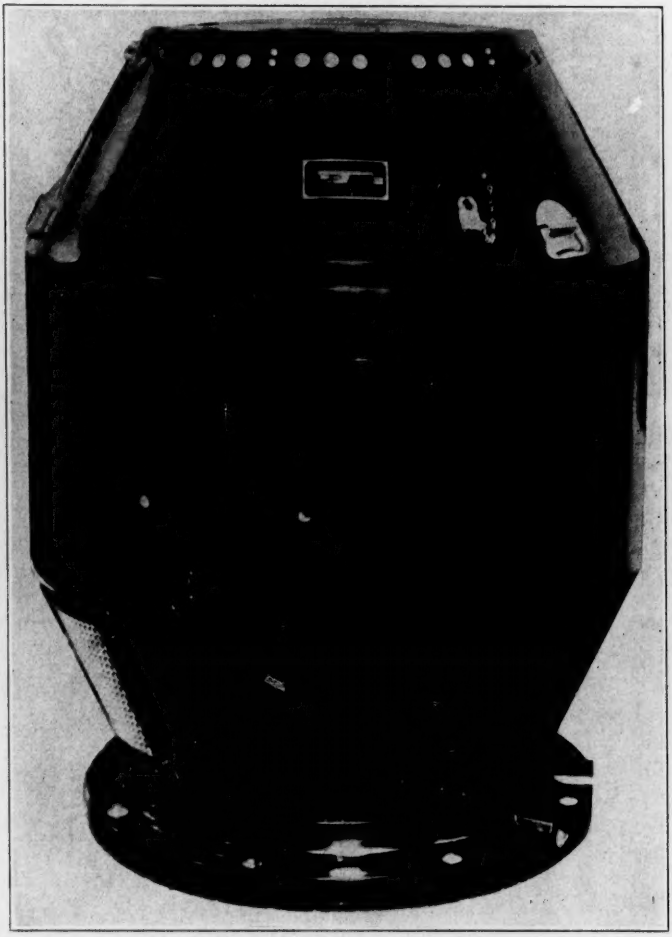


PLATE Q.—THE ARMA COMPASS. SHOWING THE COMPLETE BINNACLE STAND WITH COVERS AND DOORS IN WHICH THE COMPASS IS SUSPENDED ON A SPRING MOUNTING.

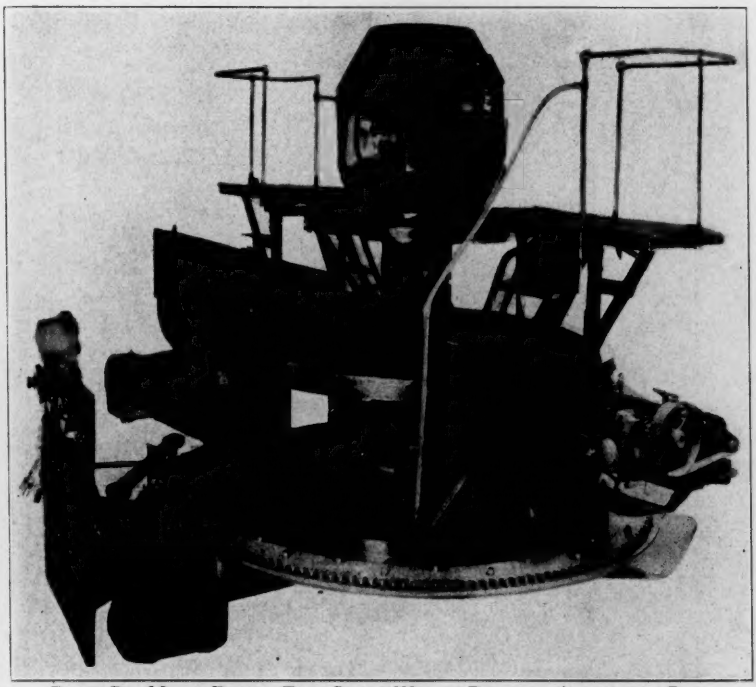


PLATE R.—MOTOR-DRIVEN TEST STAND WHICH PRODUCES ADJUSTABLE ROLL, PITCH AND YAW ANGLES TO THE MASTER COMPASS AND BINNACLE, SHOWN BOLTED TO THE COUNTER-BALANCED PLATFORM OF THE MACHINE.

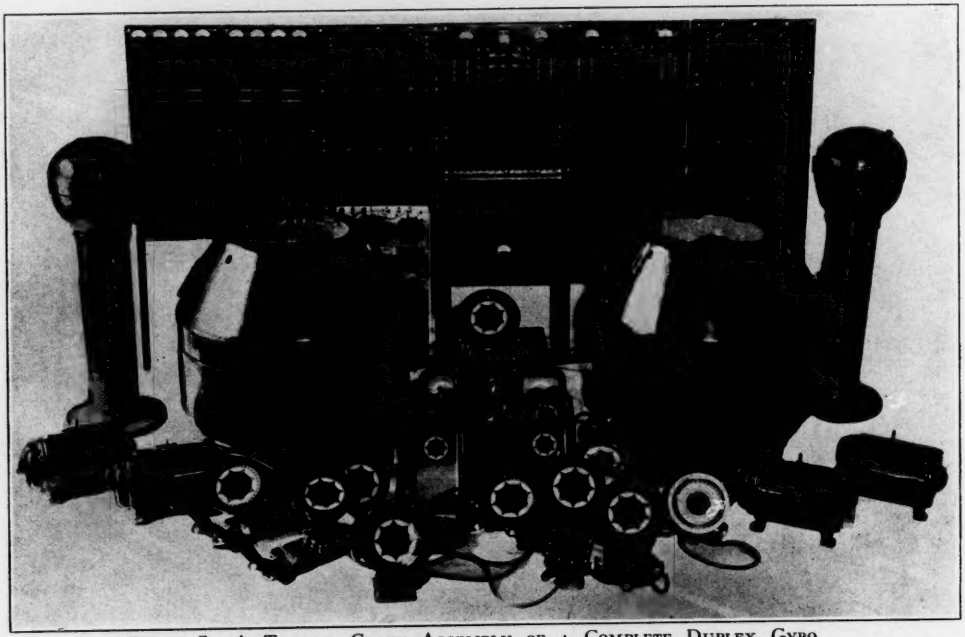


PLATE S.—A TYPICAL GROUP ASSEMBLY OF A COMPLETE DUPLEX GYRO COMPASS EQUIPMENT FOR A BATTLESHIP.

ported by means of a gimbal ring mounted on thwartship trunnions in a binnacle (see Plate J). The binnacle protects the compass and has removable doors and a detachable cover. An east elevation of the complete compass in its binnacle is shown in Plate K.

The modern Sperry Gyro Compass is the result of numerous modifications and improvements which are recorded as follows:

(*a*) Mark I Mod. O, 11 July, 1912, equipped with floating ballistic and a binnacle stand for battleships.

(*b*) Mark II Mod. O, 23 June, 1913, equipped with a floating ballistic and a binnacle stand for submarines.

(*c*) Mark III Mod. O, 1 April, 1918, has two rotors and is for use on destroyers.

(*d*) Mark IV Mod. O, 2 January, 1920, has two rotors with sleeve bearings and is for use on transports and destroyers.

(*e*) Mark V Mod. O, 28 February, 1921, same as Mark II M. B. except that the rotor bearings were increased in size.

(*f*) Mark II M. B., 7 April, 1922, equipped with a mercury ballistic and can be placed in a battleship or submarine type of binnacle stand.

(*g*) Mark VI Mod. O, 15 June, 1922, has a direct current rotor with 70-volt follow-up.

(*h*) Mark VIII Mod. O, 20 February, 1923, same as Mark VI Mod. O, except that the rotor is driven by alternating current and the follow-up is 22½ volts.

(*i*) Mark VIII Mod. 1, 20 June, 1924, same as Mark VIII Mod. O, except that the follow-up is seventy (70) volts.

(*j*) Mark II Mod. 16, 12 March, 1926, same as Mark II M. B. except that the finger type of transmitter was replaced with a commutator type of transmitter.

(*k*) Mark V Mod. 1, 12 March, 1926, same as Mark V. Mod. O, except that the finger type transmitter was replaced by a commutator type transmitter.

(*l*) Mark X Mod. O, 14 April, 1926, equipped with a 125-pound rotor, has a double-speed synchro-transmission system.

(*m*) Mark X Mod. 1, 29 March, 1928, same as Mark X Mod. O except that the mercury ballistic has four boxes and is of the swinging type.

(*n*) Mark IX Mod. O, 17 May, 1928, same as Mark VIII Mod. 1 except that the transmission system is self-synchronous with single (1) and thirty-six (36) speed transmitters.

(*o*) Mark X Mod. 3, 10 October, 1929, same as Mark X Mod. 1 except that it has an amplifier follow-up system.

(*p*) Mark XI Mod. 1, 5 September, 1930, has a rotor in between the sizes of the Mark IX Mod. O and the Mark X Mod. O and the rotor runs at a greater speed than all previous Marks with an amplifier follow-up system.

(*q*) Mark XI Mod. 2, 24 April, 1931, is the same as the Mark XI Mod. 1 except that it has large transmitters and a modified follow-up amplifier.

(*r*) Mark XI Mod. 1A, 14 March, 1933, same as Mark XI Mod. 1 except that the transmitters were replaced with a larger type.

The Arma Gyro Compass.—The latest type of Arma gyro compass employs *two* gyroscopic rotors or wheels, each weighing 25 pounds, revolving at 12,000 R.P.M., in a case and in a helium vacuum to reduce windage losses. The rotor and case constitute a single three-phase induction motor, the rotor being the secondary or squirrel cage element fitted to the interior rim of the rotor and the case containing the stator or primary winding as shown in Plate L. The two rotors with their shafts, bearings, motor windings, and vacuum case, together with the oil damping system, damping cut-out magnet, follow-up magnets, emergency azimuth scale or card, levels and adjustable leveling weights are termed the sensitive element (see Plate M) and are supported by means of a hollow steel sphere, the sphere being secured to the frame which supports the above. The sphere is floated in a bowl of mercury (see Plate N). The sphere also contains the collector rings for the three leads to the motor. The mercury bowl is oscillated by means of a motor, an eccentric and connecting linkage. The spider (see Plate O) carries the follow-up motor, follow-up arms and control coil, speed correcting mechanism, damping cut-out switch, and the self-synchronous commutator transmitter with a compass card on it which reproduces the master compass readings to the various parts of the ship by the use of repeating instruments designated as repeater compasses. The compass frame is composed of

the spider and lower bowl, the lower bowl carrying the weight of the entire compass proper as described above and this in turn is supported by gimbal rings within the binnacle stand mounted on 'thwartship trunnions as shown in Plate P. The entire binnacle stand with cover and doors is shown in Plate Q.

The modern Arma Gyro Compass is the result of numerous modifications and improvements which are recorded as follows:

(*a*) Mark I Mod. O, 30 June, 1922, has three rotors, step-by-step follow-up system of six (6) poles.

(*b*) Mark II Mod. O, 20 June, 1923, same as Mark I Mod. O except that the follow-up has twelve (12) poles and the damping system has a damping cut-out.

(*c*) Mark III Mod. O, 23 July, 1925, same as Mark II Mod. O except that it has an amplifier follow-up system, with Arma commutator type transmitter.

(*d*) Mark III Mod. 1, 16 November, 1925, same as Mark III Mod. O except that it has G. E. induction type transmitters.

(*e*) Mark IV Mod. O, 23 November, 1927, has two rotors, upper spider is open and field control of the follow-up motor.

(*f*) Mark V Mod. O, 26 June, 1928, the gyros, damping system, etc., are enclosed in a sphere and has kerosene for flotation and a wire suspension.

(*g*) Mark IV Mod. 1, 25 May, 1929, same as Mark IV Mod. O except upper spider is closed.

(*h*) Mark IV Mod. 2, 25 July, 1931, same as Mark IV Mod. 1 except that the follow-up motor armature is controlled.

(*i*) Mark VI Mod. O, 17 February, 1932, same as Mark IV Mod. 2 except that kerosene is used for damping the binnacle being smaller in diameter and for use on submarines with D. C. supply.

(j) Mark VI Mod. 1, 23 February, 1932, same as Mark VI Mod. O except for use on destroyers with A. C. supply.

ACCEPTANCE TESTS OF GYRO COMPASSES.

All gyro compass equipments purchased for the U. S. Naval service, are required to pass a prescribed acceptance test in the Material Laboratory at the Navy Yard, New York, before they are installed aboard ships. The character of the tests varies from time

to time depending on the accuracy requirements and the additional improvements incorporated to accomplish the results. In general, the laboratory test conditions simulate as closely as practicable, actual ship conditions of moderate and extreme roll, pitch and yaw. This is accomplished by mounting the completely assembled compass on a special machine termed a Scorsby test stand, which may be adjusted and operated to give the desired motions and angles in three planes. Plate R shows a gyro compass mounted on a Scorsby test stand undergoing the acceptance tests. Certain tests are conducted with the stand in motion, while for convenience, other tests are carried through with the stand at rest.

CONCLUSION.

The gyro compass which has been described up to this point, is termed a *master* gyro compass when used aboard a ship. This is for the reason that it is placed below decks in a protected compartment and it in turn, through a follow-up system, energizes *repeater* compasses which indicate the same headings as the master compass. The repeater compasses are placed at important stations throughout the ship so that the ship's heading may be noted without the necessity of sending word to the master compass compartment.

A duplex gyro compass equipment is comprised of the following essential items:

(*a*) Two master gyro compasses.
(*b*) Two control panels.
(*c*) Two repeater panels.
(*d*) Four motor-driven generators (gyro drive).
(*e*) Eight repeater compasses, bearings, single dial.
(*f*) Six repeater compasses, steering, double dial.
(*g*) Two repeater compasses, bearing, double dial, concentric.
(*h*) Two bearing repeaters stands.
(*i*) Five alarm bells and annunciators.

A typical group assembly of a complete duplex outfit for a battleship, is shown in Plate S covering the most recent equipment. For the smaller types of ships such as destroyers and submarines, the items of equipment are correspondingly reduced to suit the needs of the service.

PROPOSED METHOD OF COMPUTING WEIGHT FACTORS OF HEAT INSULATING MATERIALS FOR PIPE COVERINGS.

By Lieutenant Ralph R. Gurley, U.S.N.

In a service where fifty-two tons of heat insulating material are required for one capital ship and where a value of five hundred dollars is placed on a weight reduction of one ton in the engineering plant, it may well be imagined that a factor combining heat insulating value with weight of insulating material could be of great value. The insulating value of a material is gaged by the heat loss in B.T.U.'s per square foot of surface per hour per degree F. temperature drop through the material. To couple this value with weight per cubic foot and arrive at an equable factor for comparison of different materials is a fairly simple matter where flat surfaces are concerned. But in the case of pipe covering, where the heat loss varies as a logarithmic function of the inner and outer radii of the cover and these radii differ on different pipe sizes, the problem is not so simple. There is described herein the writer's proposed method for comparing pipe covering materials on a basis of insulating properties and weight. Acknowledgment is made of valuable suggestions freely given by Mr. W. P. Sinclair, Assistant Mechanical Engineer, in charge of testing heat insulating materials at the Engineering Experiment Station.

On Plate I are plotted the conductivity curves of the pipe covering materials used in the following paragraphs to develop factors for comparative evaluation of such materials. These curves are plotted from data obtained on this Station's pipe-covering testing apparatus, except the curve for 85 per cent Magnesia, which is taken from Heilman.*

The Heat Loss curves of Plates III to VI, inclusive, and Plate IX, are plotted from computed results obtained by substituting the appropriate values of conductivity from Plate I in formulae for determining heat losses through pipe coverings.* The ordinates of

* "Heat Losses Through Insulating Materials," R. H. Heilman, Mech. Eng., Oct. 1924, pp. 593-606.

these curves are " thickness of cover in inches "; the abscissae are " B.T.U.'s heat loss from surface of covering per foot length of pipe." The development of the curves of Plates III to VI, inclusive, and Plate IX, is illustrated by the computation of one point for 85 per cent Magnesia pipe covering, plotted on Plate IV:

(1) B.T.U. loss per hour per square foot of cover surface $= h =$

$$\frac{K\,(T_1 - T_2)}{r_2 \log_e \left(\frac{r_2}{r_1}\right)}$$

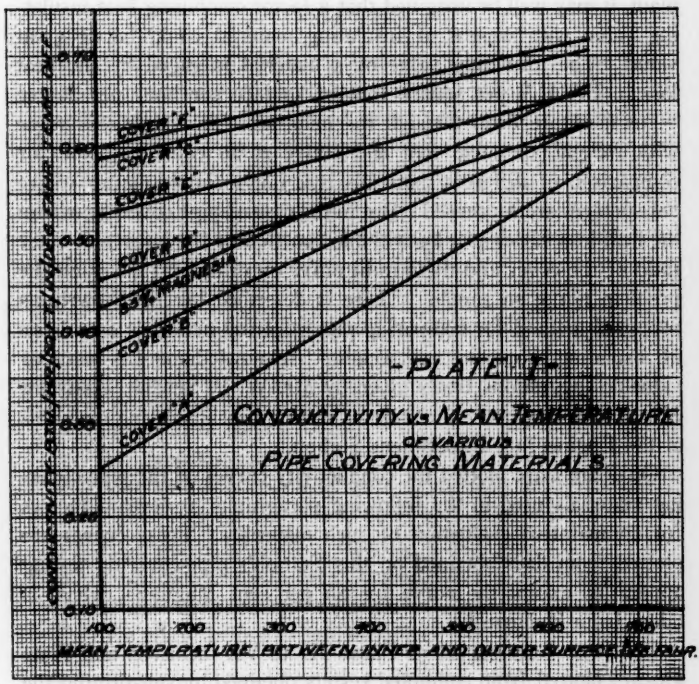


TABLE 1 VALUES OF $r_1 \log (r_2/r_1)$

Pipe size in.	r_1	1 in. r_2	1 in. $r_1 \log_e \frac{r_2}{r_1}$	1½ in. r_2	1½ in. $r_1 \log_e \frac{r_2}{r_1}$
½	0.420	1.420	1.730	1.920	
¾	0.525	1.525	1.625	2.025	
1	0.657	1.657	1.532	2.157	
1¼	0.830	1.830	1.448	2.330	
1½	0.950	1.950	1.400	2.450	
2	1.187	2.187	1.335	2.687	
2½	1.437	2.437	1.288	2.937	
3	1.750	2.750	1.240	3.250	
3½	2.000	3.000	1.216	3.500	
4	2.250	3.250	1.190	3.750	
4½	2.500	3.500	1.177	4.000	
5	2.781	3.781	1.161	4.281	
6	3.312	4.312	1.138	4.812	
7	3.812	4.812	1.117	5.312	
8	4.312	5.312	1.101	5.812	
9	4.812	5.812	1.109	6.312	
10	5.375	6.375	1.085	6.875	
12	6.370	7.375	1.073	7.875	
14	7.000	8.000	1.057	8.500	
16	8.000	9.000	1.050	9.500	
18	9.000	10.000	1.044	10.500	

TABLE 2 VALUES OF $\frac{564}{D^{2.15}}$

(D in inches)

D	$\frac{564}{D^{2.15}}$	D	$\frac{564}{D^{2.15}}$	D	$\frac{564}{D^{2.15}}$
3.00	458	6.0	401	10.5	361
3.25	451	6.5	385	11.0	357
3.50	445	7.0	390	11.5	354
3.75	439	7.5	345	12.0	351
4.00	433	8.0	380	12.5	348
4.25	428	8.5	375	13.0	346
4.50	423	9.0	371	14.0	341
5.0	415	9.5	367	15.0	337
5.5	408	10.0	364	16.0	333

TABLE 3 ASSUMED CANVA

Pipe size in inches	Covering 1 in. thick. Temp diff., pipe to room 200	300	400	500	600	Covering 1½ in. thic Temp diff., pipe to ro 200	300	400	500
½	22	34	46	58	71	15	23	32	41
¾	23	35	48	60	74	16	25	35	44
1	24	37	50	64	78	17	27	36	45
1¼	26	40	54	68	82	18	27	38	48
1½	27	42	56	71	85	19	28	40	51
2	29	44	58	73	88	20	32	42	54
2½	30	45	60	76	91	21	33	45	57
3	31	46	62	78	94	22	34	47	59
3½	32	48	64	80	97	23	35	48	60
4	34	50	66	82	99	24	36	49	62
4½	34	51	67	83	100	25	37	50	64
5	35	52	69	86	103	26	38	51	65
6	36	53	70	87	105	26	39	52	67
7	37	55	72	88	107	27	40	54	68
8	38	56	74	90	109	28	41	56	69
9	39	57	76	92	111	29	42	57	70
10	40	58	77	94	113	30	43	58	71
12	40	59	78	96	114	30	44	59	73
14	41	60	79	98	116	31	45	60	75
16	42	61	80	100	118	31	46	62	77
18	43	62	81	101	119	31	47	63	79

$r_1 \log (r_2/r_1)$ FOR COVERINGS OF VARIOUS THICKNESSES ON DIFFERENT-SIZED PIPES

Thickness of Covering

1½ in.		2 in.		2½ in.		3 in.		4 in.	
r_1	$r_1 \log_e \frac{r_2}{r_1}$	r_1	$r_1 \log_e \frac{r_2}{r_1}$	r_1	$r_1 \log_e \frac{r_2}{r_1}$	r_1	$r_1 \log_e \frac{r_2}{r_1}$	r_1	$r_1 \log_e \frac{r_2}{r_1}$
1.920	2.920	2.420	4.233	2.920	5.440	3.420	7.165	4.420	10.400
2.023	3.733	2.525	3.045	3.025	5.264	3.525	6.710	4.525	9.760
2.157	2.563	2.657	3.710	3.157	4.950	3.657	6.278	4.657	9.110
2.330	2.402	2.830	3.470	3.330	4.622	3.830	5.855	4.830	8.500
2.450	2.322	2.950	3.340	3.450	4.445	3.950	5.630	4.950	8.170
2.647	2.194	3.147	3.145	3.647	4.177	4.147	5.362	5.147	7.686
2.937	2.082	3.437	2.966	3.937	3.965	4.437	5.000	5.437	7.220
3.250	2.010	3.750	2.856	4.250	3.770	4.750	4.740	5.750	6.840
3.500	1.959	4.000	2.770	4.500	3.647	5.000	4.500	6.000	6.560
3.750	1.913	4.250	2.700	4.750	3.504	5.250	4.450	6.250	6.325
4.000	1.890	4.500	2.640	5.000	3.465	5.500	4.340	6.500	6.210
4.281	1.845	4.781	2.588	5.281	3.383	5.781	4.236	6.781	6.043
4.812	1.795	5.312	2.507	5.812	3.266	6.312	4.071	7.312	5.790
5.312	1.764	5.812	2.448	6.312	3.190	6.812	3.935	7.812	5.624
5.812	1.733	6.312	2.403	6.812	3.114	7.312	3.800	8.312	5.440
6.312	1.710	6.812	2.370	7.312	3.060	7.812	3.700	8.812	5.325
6.875	1.684	7.375	2.334	7.875	3.007	8.375	3.707	9.375	5.220
7.375	1.660	7.875	2.285	8.375	2.932	8.875	3.614	10.375	5.040
8.500	1.654	9.000	2.282	9.500	2.900	10.000	3.566	11.000	4.950
9.500	1.630	10.000	2.236	10.500	2.852	11.000	3.500	12.000	4.800
10.500	1.630	11.000	2.203	11.500	2.817	12.000	3.455	13.000	4.750

$\frac{564}{D^{0.75}}$

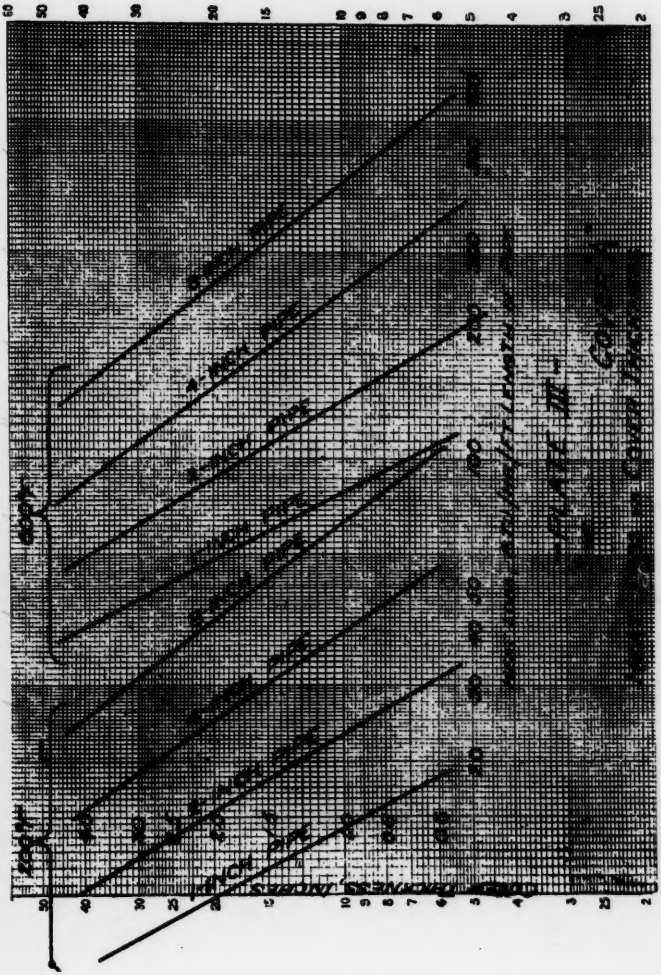
$\frac{564}{D^{0.75}}$	D	$\frac{564}{D^{0.75}}$
361	17.0	330
357	18.0	325
354	19.0	322
351	20.0	319
349	21.0	316
346	22.0	313
341	23.0	310
337	24.0	306
332		

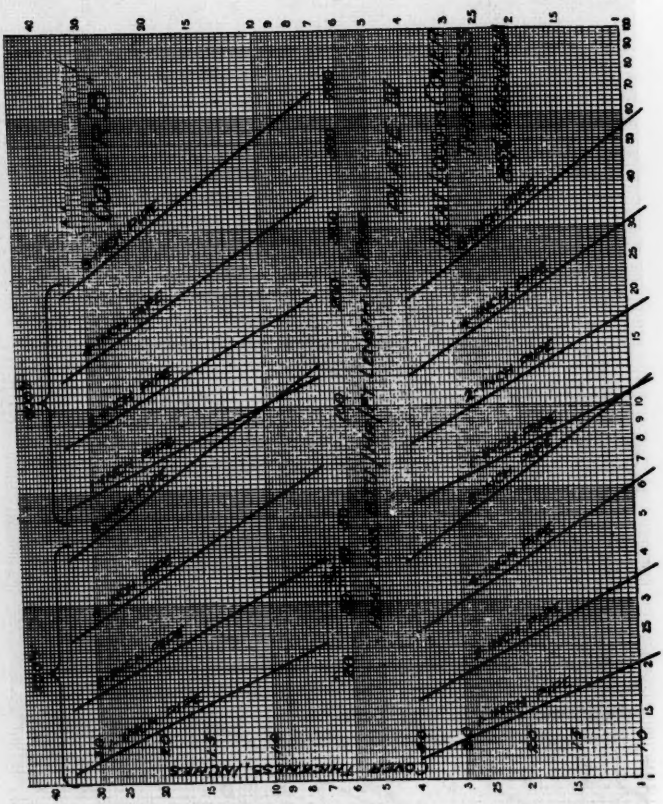
PLATE II

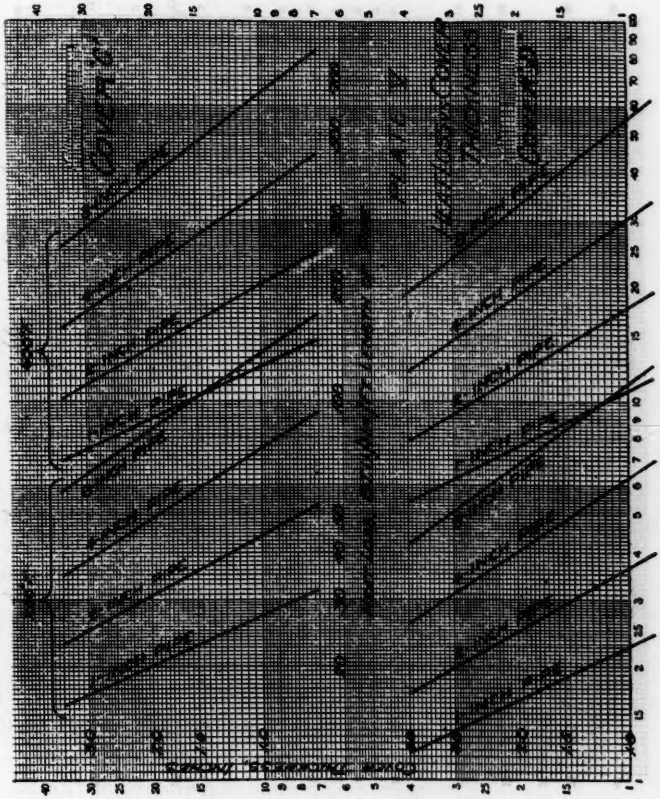
HEILMAN'S TABLES.

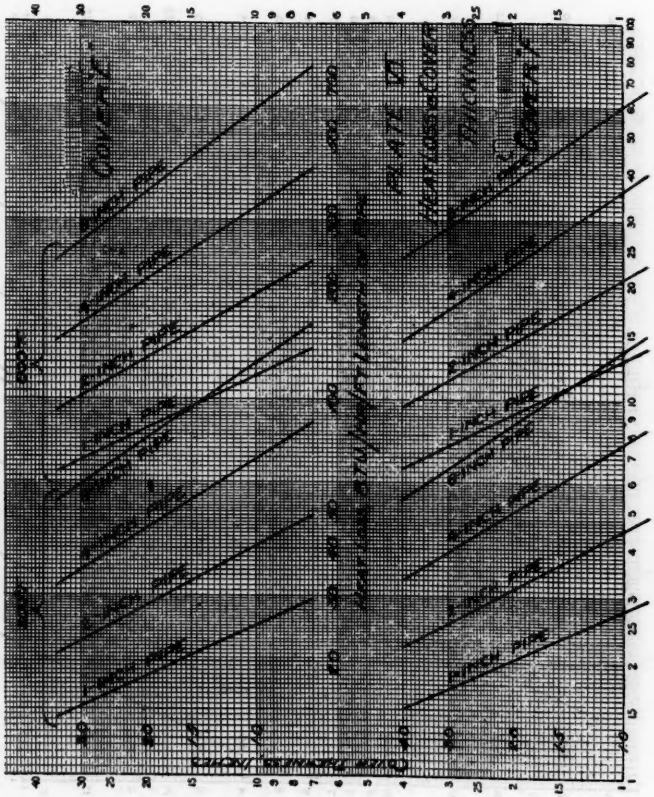
MED CANVAS TEMPERATURE DIFFERENCE FOR BEST-GRADE COVERINGS

ng 1½ in. thick			Covering 2 in. thick					Covering 3 in. thick					Covering 4 in. thick				
iff., pipe to room			Temp. diff., pipe to room					Temp. diff., pipe to room					Temp. diff., pipe to room				
400	500	600	200	300	400	500	600	200	300	400	500	600	200	300	400	500	600
32	41	50	10	18	25	31	38	8	13	18	22	27	5	8	12	15	14
35	44	53	11	19	26	33	40	8	14	19	23	28	5	8	13	16	20
36	45	56	12	20	27	34	42	8	14	20	24	30	6	9	14	18	23
38	48	59	13	21	29	35	46	9	15	21	26	31	6	10	15	19	20
40	51	61	14	22	29	37	47	9	15	21	26	33	6	11	16	20	21
42	54	65	15	23	31	39	49	9	16	22	28	35	7	12	17	21	22
45	57	68	16	24	33	41	52	10	17	23	31	37	7	13	18	23	23
47	59	71	17	25	35	43	55	11	17	24	32	39	8	14	19	24	24
48	60	73	18	26	37	45	58	11	18	25	33	40	8	14	20	25	25
49	62	75	19	28	38	47	60	11	18	26	33	41	9	15	21	26	26
50	64	77	19	29	40	50	63	12	19	27	34	42	9	15	21	27	28
51	65	78	20	30	41	52	63	12	19	28	35	44	10	16	22	28	29
52	67	80	20	30	42	54	64	13	20	29	37	45	10	16	23	29	30
54	68	82	21	31	43	55	66	13	21	30	39	47	11	17	23	30	32
56	69	84	21	31	44	56	67	14	22	31	40	48	11	17	24	31	33
57	70	86	22	32	45	57	68	14	22	32	41	49	11	18	25	32	34
58	71	88	22	33	46	59	70	15	23	33	43	51	12	19	26	34	40
59	73	90	23	34	48	61	72	15	24	34	44	53	12	20	27	35	42
60	75	92	23	35	49	62	74	16	25	35	45	55	13	20	28	36	43
62	77	94	24	36	50	63	76	16	26	36	46	56	13	21	28	37	44
63	79	95	24	37	51	64	78	17	27	37	47	57	13	21	29	37	44









where

K = conductivity of cover material at mean temperature, pipe to canvas cover.

T_1 = pipe temperature, degrees F.

T_2 = canvas cover temperature, degrees F.

r_1 = inside radius of cover, inches.

r_2 = outside radius of cover, inches.

This value of h is converted to B.T.U. loss per hour per square foot of pipe surface:

$$H = h \times \frac{r_2}{r_1} \tag{2}$$

and then to B.T.U. loss per hour per foot length of pipe:

$$H^1 = H \times \frac{\pi d}{12} \text{ where d = pipe diameter in inches.} \tag{3}$$

Temperature difference from canvas cover to room was computed by Heilman's formula:

$$T_d = \frac{272.5\ h}{h + \frac{564}{D^{0.19}}} \tag{4}$$

Heilman's convenient tables for $r_2 \log_e \frac{r_2}{r_1}$, and for $\frac{564}{D^{0.19}}$ were used throughout. (See Plate II.)

Computation of heat loss for 85 per cent magnesia, 8-inch pipe, 2-inch cover, 600 degrees F. pipe temperature:

Assume room temperature of 70 degrees F. From Table 3, Plate II, for the conditions of the problem, a temperature difference of 63 degrees F. from canvas cover to room may be assumed.

Temperature of canvas cover = 70 + 63 = 133 degrees F.

Mean temperature difference, pipe to cover =

$$\frac{600 + 133}{2} = 366.5 \text{ degrees F.}$$

From the 85 per cent Magnesia curve on Plate I it is noted that K, the conductivity of the material, is 0.543.

K = 0.543

From Table 1, Plate II:

$$r_1 = 4.312$$

$$r_2 = 6.312$$

$$r_2 \log_e \frac{r_2}{r_1} = 2.405$$

Substituting in equation (1) above:

$$h = \frac{0.543\ (600-133)}{2.405} = 105.0$$

From Table 2, Plate II:

$$\frac{564}{D^{0.19}} = 348$$

Substituting in equation (4) above:

$T_d = \frac{272.5 \times 105}{105 + 348} = 63$ degrees F., which checks with the assumed temperature difference from cover to room. Therefore the value of h as computed above is correct.

$H = 105.0 \times \frac{6.312}{4.312} = 153.8$, Substituting in Equation (2).

$H^1 = 153.8 \times \frac{\pi \times 8}{12} = 321$ B. T. U.'s heat loss per hour per foot length of pipe.

Thus, the heat loss curves for each material were developed on the basis of B.T.U.'s loss per foot length of pipe. This factor was plotted against thickness of pipe covering in inches. A curve was developed for each of the following pipe sizes: 1-inch, 2-inch, 4-inch, 8-inch. This range of pipe sizes covers the majority of pipes on board ship and an insulating and weight factor based on performance over this range will be applicable to all sizes. One set of heat loss curves for each material was based on 200 degrees F. pipe temperature and the other on 600 degrees F. pipe temperature. Where a considerable difference occurs between the final factors for any material at these two temperatures, the factor at intermediate temperatures can be obtained by interpolation.

The heat loss curves described above are straight lines on double logarithmic paper. The variation in the slope between these curves for all materials under consideration is encompassed in an angle of 4.3 degrees. The variation, therefore, between the average and the most divergent material is of the order of 2.15 degrees. This deviation of slope could result in an error of 0.125 inch thickness, maximum, in a cover thickness difference of 2 inches. Such a difference will not be encountered in practice and the thickness error will be correspondingly reduced. This error will invariably be less than the smallest graduation (⅛ inch) in which coverings are manufactured.

It was noted that the ratio of heat losses of any two materials at any similar cover thickness for any pipe size and temperature, varied only slightly except when one of the materials was a mineral wool. When comparing heat losses of mineral wools with that of 85 per cent Magnesia, which was used as a standard, the ratio of this factor for all cover thicknesses and pipe sizes was practically constant for any given pipe temperature, but differed considerably between 200 degrees F. and 600 degrees F. pipe temperatures. This difference in behavior between mineral wools and the other materials is to be expected after noting the marked difference in slope between their conductivity curves.

On Plate VII there appears a group of curves whose slope is the average of the slope of all the heat loss curves shown on Plates III to VI, inclusive. The curves of the different materials are so displaced from each other horizontally that the ratio of abscissae equals the ratio of heat insulating properties as indicated in the grand average of Table I. The ratio of the abscissa of the curve of 85 per cent Magnesia to that of the curve of any other material at the same thickness is the "heat insulating factor" of that material. It is noted that the factors compare the materials with 85 per cent Magnesia. This is the case throughout these computations. On Plate VII the "thickness factor" of a material is the ratio of the ordinate of the curve of that material to the ordinate of the curve of 85 per cent Magnesia on the same vertical line.

In other words, the "heat insulating factor" (f_h) of a material is the ratio of the heat loss through a certain thickness of 85 per cent Magnesia to the heat loss through the same thickness of the

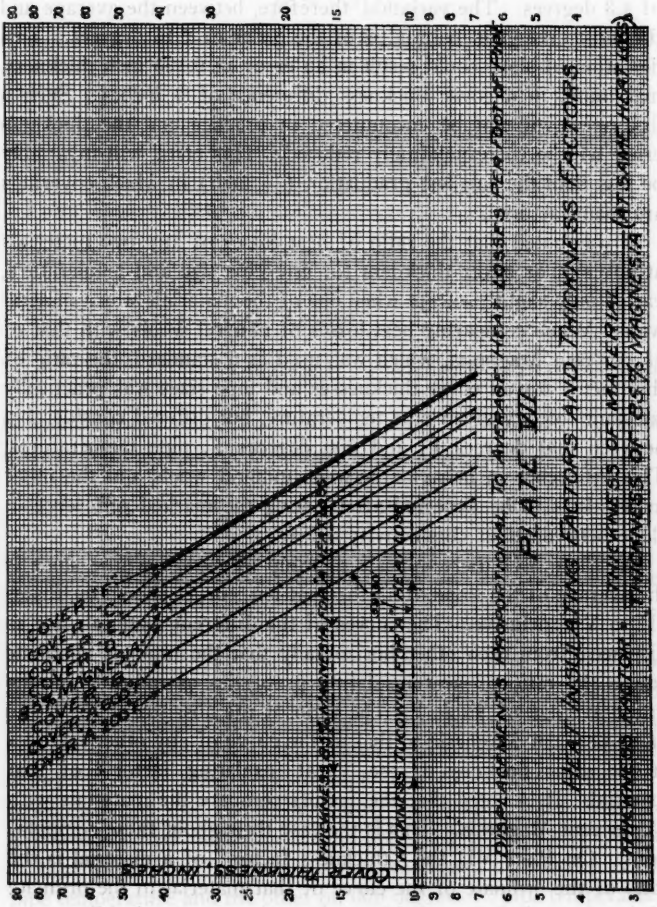
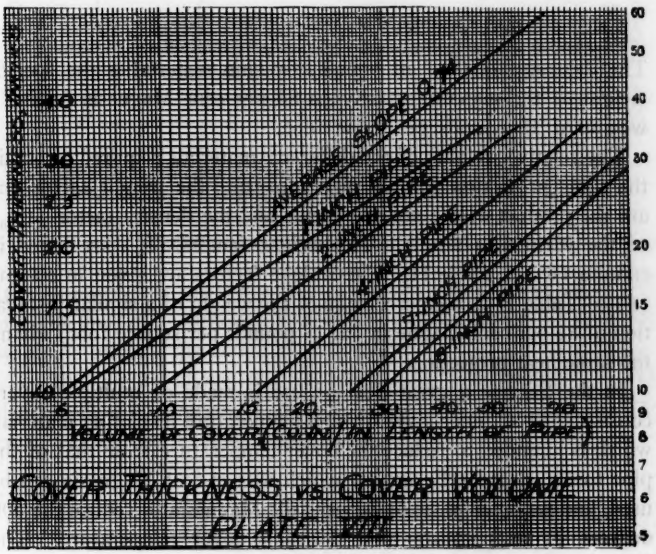


PLATE XIII
Cover Thickness Factors
Cover Thickness Inches

material under consideration under similar pipe conditions. (See column 1, Table II.)

The "thickness factor" (f_t) is the ratio of the thickness of cover of the material under consideration to the thickness of a cover of 85 per cent Magnesia required to give the same protection under similar pipe conditions. (See column 2, Table II.)

If some definite relation can be found between cover thickness and cover volume, then the thickness factor can be transmitted to a "volume factor." On Plate VIII are drawn the curves of cover thickness versus cover volume for various pipe sizes. For practical purposes these curves can be assumed to be parallel to the average curve. The slope of this curve indicates that volume of cover is practically proportional to the 1.35 power of the thickness.



COVER THICKNESS vs. COVER VOLUME
PLATE VIII

Therefore the relation between the volume of two different types of cover giving the same protection will be:

$$\frac{V_1}{V_2} = \left(\frac{t_1}{t_2}\right)^{1.35}$$

Let V_2 represent the volume and t_2 the thickness of an 85 per cent Magnesia cover, then we have

$$\frac{V_1}{V_2} = (f_t)^{1.35}$$

But the "volume factor" (f_v) is the ratio of the volume of a certain material, required as pipe covering to allow a certain heat loss, to the volume of an 85 per cent Magnesia cover which will give the same heat loss under the same pipe conditions:

$$\text{Therefore } \frac{V_1}{V_2} = f_v$$

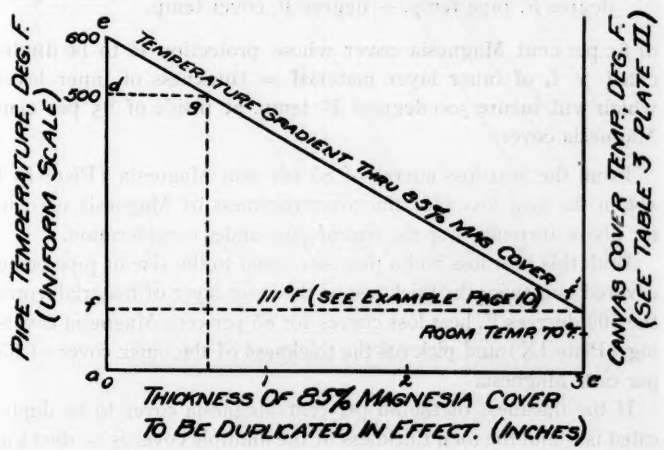
$$\text{and } f_v = (f_t)^{1.35}$$

The "density factor" of a pipe covering material is the specific weight of the material relative to 85 per cent Magnesia having a weight of 18 pounds per cubic foot.

The relative weights of the different materials required to obtain the same protection for the pipe constitute the weight factor and are the product of the volume factor and the density factor ($f_v f_d$) of the various materials. The weight factors (f_w) are listed in column (6) of Table II. The weight factors are given in column (6) of Table II as the percentage of the weight of a similar installation of 85 per cent Magnesia (at 18 pounds per square foot) giving the same heat protection.

In the Service a great deal of use is made of multiple covers consisting of an inner layer of high temperature insulating material, which is intended to reduce the cover temperature from that of the pipe to 500 degrees F. against which 85 per cent Magnesia can be used, and an outer layer of 85 per cent Magnesia to reduce the 500 degrees F. temperature to a desirable cover temperature. The present practice is to specify a certain thickness of inner and outer layers of material. Thus the manufacturer, regardless of the efficiency of his material, must furnish it in the specified thick-

nesses. Considerable saving in weight could be effected if the manufacturer were allowed to furnish his multiple cover in the minimum thicknesses which will produce the desired insulating effect. A weight factor comparing the weight of such a multiple cover with the weight of a cover of 85 per cent Magnesia with the same insulating effect can be determined by proper use of the thickness factors and density factors developed above for the various materials. The derivation of the necessary formulae and the solution of one example follow:



It is assumed that the temperature gradient through the cover is a straight line, ef. Although this is not strictly true, it errs on the safe side because the actual gradient sags.

In the Figure above, the Canvas Cover Temperature of 111 degrees F. is 70 degrees F. plus the "Canvas Temperature Difference," 41 degrees F. taken from Table 3, Plate II.

By similar triangles

$$\frac{dg}{ff} = \frac{de}{fe}, \text{ or } \frac{dg}{ac} = \frac{de}{fe}$$

dg = thickness 85 per cent Magnesia required to give a cover temperature of 500 degrees F.

ac = thickness of 85 per cent Magnesia cover, the heat protection of which is to be duplicated.

de = pipe temperature degrees F. — 500.

fe = pipe temperature degrees F. — Canvas Cover Temperature degrees F.

dg $\times f_t$ of material to be used as inner layer = thickness of inner layer required to insure 500 degrees F., temperature at inside of 85 per cent Magnesia cover

therefore:

(1) $\frac{\text{degree F. pipe temp.} - 500}{\text{degree F. pipe temp.} - \text{degree F. cover temp.}} \times$ Thickness of 85 per cent Magnesia cover whose protection is to be duplicated $\times f_t$ of inner layer material = thickness of inner layer which will insure 500 degrees F. temp. at inside of 85 per cent Magnesia cover.

From the heat loss curves of 85 per cent Magnesia (Plate IV) obtain the heat loss (for the cover thickness of Magnesia used in the above formula) for the size of pipe under consideration.

With this heat loss and a pipe size equal to the size of pipe being covered plus twice the thickness of the inner layer of material, enter the 500 degrees F. heat loss curves for 85 per cent Magnesia covering (Plate IX) and pick off the thickness of the outer cover of 85 per cent Magnesia.

If the thickness of the 85 per cent Magnesia cover to be duplicated is t_1 and the total thickness of the multiple cover is t_2, then the volume factor of the multiple covering would be

$$f_v = \frac{v_2}{v_1} = \left(\frac{t_2}{t_1}\right)^{1.35}$$

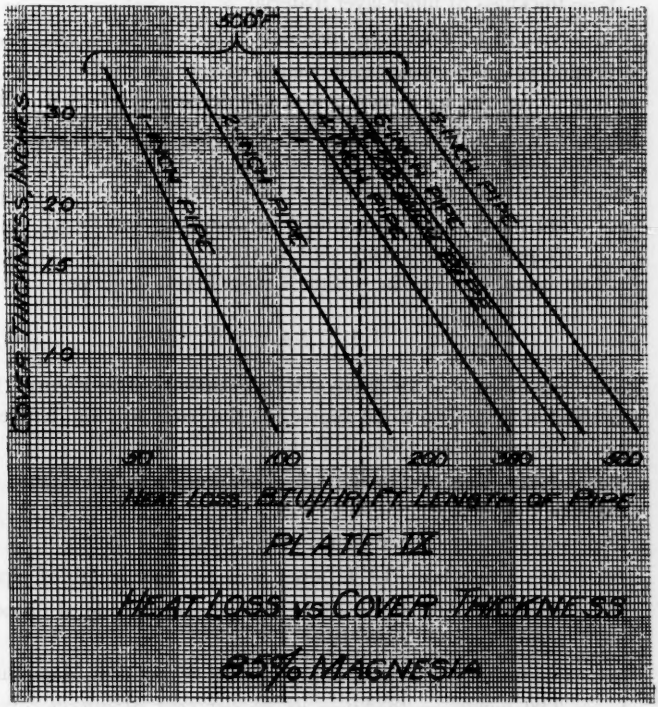
If the density of the multiple covering were the same as that of the 85 per cent Magnesia covering, its weight factor would be:

$$f_w = \frac{v_2 \times d_1}{v_1 \times d_1} = \frac{v_2}{v_1} = \left(\frac{t_2}{t_1}\right)^{1.35}$$

If the density of the multiple covering were d_2 then the weight factor of the multiple covering would be:

$$f_w = \frac{v_2 \times d_2}{v_1 \times d_1} = \frac{v_2}{v_1} f_d = f_d \left(\frac{t_2}{t_1}\right)^{1.35}$$

where f_d = density factor of the multiple covering.



If the multiple covering were composed of an inner layer material having a density d_2 and outer layer of 85 per cent Magnesia or a material having the same density as 85 per cent Magnesia, the weight factor of the multiple covering would be:

$$\frac{v_3 \times d_2 + (v_2 - v_3)\, d_1}{v_1 \times d_1} = \frac{v_3 \times d_2}{v_1 \times d_1} + \frac{v_2 - v_3}{v_1} = \frac{v_3}{v_1} \times \frac{d_2}{d_1} + \frac{v_2}{v_1} - \frac{v_3}{v_1}$$

Since $\left(\frac{V_2}{v_1}\right) = \left(\frac{t_2}{t_1}\right)^{1.35}$ and $\frac{V_3}{v_1} = \left(\frac{t_3}{t_1}\right)^{1.35}$ and $\frac{d_2}{d_1} = f_d$

and f_d = density factor of inner layer material

Then

$$f_w = \left(\frac{t_3}{t_1}\right)^{1.35} \times f_d + \left(\frac{t_2}{t_1}\right)^{1.35} - \left(\frac{t_3}{t_1}\right)^{1.35} = \left(\frac{t_2}{t_1}\right)^{1.35} + \left(\frac{t_3}{t_1}\right)^{1.35} (f_d - 1)$$

t_3 = thickness of inner layer material

v_3 = volume of inner layer material

Example: Find comparative weight of a cover of "C" and 85 per cent Magnesia for 4-inch pipe at 600 degrees F. which will give the same protection as a 3-inch cover of 85 per cent Magnesia.

From Plate IV, the heat loss through a 3-inch cover of 85 per cent Magnesia at 600 degrees F. on a 4-inch pipe =

145 B.T.U.'s per square foot per hour per degrees F. temperature difference pipe to room.

From Equation (1), the thickness inner layer, "C" =

$$\frac{600-500}{600-111} \times 3 \times 1.4 = 0.86 \text{ inches}$$

Room temperature of 70 degrees F. is assumed. The Figure 111 is arrived at by adding to 70 degrees F. the cover to room temperature difference from Table 3, Plate II.

1.4 is taken from the table of "Thickness Factors," column 2, Table II.

Pipe size for outer cover = $4 + 2 \times .86 = 5.72$ inches

h = 145 = heat loss, B.T.U.'s per hour per foot length of pipe.

Temperature = 500 degrees F. = temperature inside of 85 per cent Magnesia outer layer.

*t_0 = 2.85 inches = thickness outer layer of 85 per cent Magnesia.

t_1 = 3.00 inches = thickness of 85 per cent Magnesia cover whose protection is being duplicated.

t_2 = 3.71 inches = total thickness of multiple cover.

t_3 = 0.86 inches = thickness of inner layer of Cover "C."

f_d = Density factor of "C" = 1.46.

Weight factor of multiple cover consisting of an inner layer of cover "C," 0.86 inch thick, and an outer layer of 85 per cent Magnesia, 2.85 inches thick, and duplicating the protection given by a 3-inch cover of 85 per cent Magnesia =

$$\left(\frac{3.71}{3.00}\right)^{1.35} + \left(\frac{0.86}{3.00}\right)^{1.35} (1.46-1)$$

* From Plate IX, using pipe size 5.72 inches and H = 145.

$= 1.323 + .185 \times 0.46$

$= 1.323 + .085$

$= 1.408$ or $1.408 \times 100 = 140.8$ per cent of weight of 85 per cent Magnesia

It may be desirable to compare weights of multiple cover installations made under the existing Specifications. In such a case the thicknesses of inner and outer covers are given.

Weight factor for multiple cover in this case

$$2 = \left[1 + \left(\frac{t_3}{t_2}\right)^{1.35} \times (f_{d_a} - 1)\right] \times 100$$

where t_3 = thickness inner layer

t_2 = total thickness cover

f_{da} = density factor of inner layer (from Column 4, Table II)

There are four standard thickness combinations allowed by Navy Department Specifications 32P3 of 1 February, 1927. They are listed below with their respective values of

$$\left(\frac{t_3}{t_2}\right)^{1.35}$$

Thickness Type C Cover					
t_3	t_1	t_2	$(t_3)/(t_2)$	$b = \frac{(t_3)^{1.35}}{(t_2)}$	Equation (2) becomes weight factor for multiple cover
Inner Layer	Outer Layer	Comp. Cover			$= \left[1 + b\,(f_{d_a} - 1)\right] \times 100$
1-1/32	1-1/32	2-1/16	0.5	0.392	
1-1/16	1-1/8	2-3/16	0.485	0.377	
1-1/4	1-1/4	2-1/2	0.5	0.392	
1-1/2	1-1/4	2-3/4	0.545	0.440	
2	1-1/2	3-1/2	0.571	0.470	

The factor determined in this case is, however, not a true "weight factor" because it is not based on the weight of an 85 per cent Magnesia covering giving the same protection. It is merely a factor comparing the weights of multiple covers with the weight of an 85 per cent Magnesia cover of the same thickness.

T	Cover	Pipe size	(1) Mag.	(2) Cover "A"		(3) Cover "B"		(4) Cover "D"		(5) Cover "F"		(6) Cover "E"		(7) Cover "C"	
			(a)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
200	1"	1	20.2	14.2	1.420	19.7	1.024	22.5	0.897	27.8	0.726	25.2	0.800	27.2	0.741
		2	35.0	23.2	1.510	32.0	1.092	36.8	0.951	45.2	0.774	41.1	0.850	44.5	0.786
		4	60.3	39.8	1.515	55.1	1.092	63.0	0.956	76.8	0.785	70.0	0.861	76.0	0.793
		8	108.0	71.0	1.521	98.8	1.092	111.0	0.972	135.8	0.795	125.0	0.864	133.0	0.812
	3"	1	12.75	8.0	1.592	11.5	1.107	13.5	0.943	17.2	0.742	15.3	0.832	16.8	0.760
		2	19.1	12.2	1.566	17.2	1.110	20.0	0.955	25.6	0.746	22.7	0.841	25.0	0.764
		4	29.6	18.8	1.575	26.6	1.112	31.2	0.949	39.6	0.748	35.0	0.845	38.2	0.775
		8	48.8	32.5	1.500	44.2	1.103	51.0	0.955	65.1	0.749	58.8	0.830	64.0	0.762
600	1"	1	108.0	84.0	1.286	100.2	1.075	107.0	1.010	127.2	0.849	116.0	0.930	125.0	0.864
		2	177.0	137.0	1.290	167.0	1.060	177.0	1.000	210.0	0.842	191.0	0.925	205.0	0.863
		4	306.0	243.0	1.260	286.0	1.070	303.0	1.010	360.0	0.850	328.0	0.932	355.0	0.861
		8	549.0	435.0	1.260	523.0	1.050	550.0	0.997	605.0	0.907	595.0	0.922	642.0	0.855
	3"	1	62.4	47.2	1.320	57.6	1.080	62.5	0.997	75.2	0.830	68.4	0.912	75.0	0.830
		2	93.5	70.5	1.325	86.1	1.085	92.5	1.011	112.5	0.830	102.2	0.913	111.0	0.842
		4	145.0	108.0	1.341	132.8	1.093	145.0	1.000	173.5	0.835	158.2	0.916	172.0	0.843
		8	238.5	184.0	1.300	223.0	1.070	240.0	0.994	288.0	0.829	262.0	0.911	285.0	0.838
Average 200				1.525		1.092		0.947		0.758		0.840		0.776	
Average 600				1.298		1.073		1.002		0.847		0.920		0.850	
Grand Average		200		1.525		1.082		0.975		0.802		0.880		0.812	
		600		1.298											

(a) Heat loss in B.T.U.'s/hr./deg.F. temp.diff./ft.of pipe.
(b) Insulating Factor = $\frac{\text{Heat Loss,85\% Magnesia}}{\text{Heat Loss,Other Material}}$

TABLE I.

	(1) Insulating factor (f_h)		(2) Thickness factor (f_t)		(3) Voluse factor (f_v)		(4) Density factor (f_d)	(5) Comparative value at same thickness (f_h/f_d)		(6) % of wt.of 85% Magnesia Wt.factor $f_w = f_v/f_d$ x100	
	200°F	600°F	200°F	600°F	200°F	600°F		200°F	600°F	200°F	600°F.
Cover "A"	1.525	1.298	0.480	0.637	0.372	0.543	0.675	2.26	1.92	25.2	36.6
Cover "B"	1.082		0.869		0.827		1.150	0.940		95.2	
85% Magnesia	1.000		1.000		1.000		1.000	1.000		100.0	
Cover "D"	0.975		1.050		1.070		1.390	0.701		149.0	
Cover "E"	0.880		1.220		1.306		1.348	0.658		176.0	
Cover "C"	0.812		1.400		1.575		1.460	0.556		230.0	
Cover "F"	0.802		1.450		1.655		1.668	0.481		279.5	

$f_h = \frac{\text{Heat Loss,Magnesia}}{\text{Heat Loss,Other Material}}$ (Same Thickness), $f_t = \frac{\text{Thickness,Other Material}}{\text{Thickness,Magnesia}}$ (Same Heat Loss)

$f_v = \frac{\text{Volume,Other Material}}{\text{Volume,Magnesia}}$ (Same Heat Loss), $f_d = \frac{\text{Wt./Cu.Ft.,Other Material}}{\text{Wt./cu.Ft.,Magnesia}}$

$f_w = \frac{\text{Weight,Other Material}}{\text{Weight,85\% Magnesia}}$ (Same Heat Loss)

TABLE II.

PRACTICAL CONSIDERATIONS IN BURNING CRACKED FUEL OILS.

By Lieutenant Commander Thorvald A. Solberg, U. S. N.

The May issue of this Journal covered various aspects of cracked fuel oils of the types likely to be furnished naval vessels. The following notes cover more specifically the practical considerations in connection with the use of these oils, including bunkering, heating, and combustion. Much of the information has been obtained from work on representative fuels at the Naval Boiler Laboratory and from service reports to date.

It was expected, and is still to be expected in the future, that various problems and difficulties will be encountered when using such fuels. The fact that refinery methods differ with different companies, the possibilities of varying conditions to meet various commercial needs, the influence of control variations during different stages of refining, are all factors any one of which might result in producing temporarily an oil which might cause trouble. The present state of the art of analyzing and testing oils by short methods to determine quickly whether an oil will have any unsatisfactory features is such that it precludes the possibility of preventing deliveries of undesirable oils. Continued efforts in this direction eventually may provide short tests which will enable preventing deliveries of unsatisfactory oils.

The primary purpose of the cracking processes, of which cracked fuel oil is a by-product, is to produce a greater yield of gasoline, which is effected by a re-forming of some of the various constituents in the oil into gasoline. The resultant gasoline is a better grade also than that which can be obtained with the ordinary distillation methods, the principal superiority being in its better anti-knock qualities. Justification for the use of cracking processes therefore lies not only in the attainment of greater quantities of gasoline, but also in the production of the higher grades of gasoline

which present-day internal combustion engines require. The yield of other light products generally is affected in the same manner.

The availability and the characteristics of fuel oils must be known and studied carefully for military purposes. It is absolutely necessary that naval ships be able to operate as follows with any fuel of the future:

(*a*) With no decrease in designed cruising radii.

(*b*) With no change in visibility characteristics incident to smoke or excessive stack solids. It is essential in this connection that stack solids and smoke shall not be such as to interfere with the operation of fire control mechanisms in the tops or interfere with spotters and other observers and operators.

(*c*) With no adverse change in the present flexibility of boiler control.

(*d*) Operation in Arctic waters must be feasible without requiring the installation of tank heating arrangements which are impractical from a military standpoint.

The principal troubles to be expected are concerned with:

(*a*) The formation of tank sludges and deposits either from the instability of the oil itself or from instability which results on mixing of different oils in a tank. It manifestly is impossible to remove the last remnants of oil from a tank before bunkering, and even the small percentage of mixing or blending resulting may produce instability.

(*b*) The formation of hard carbon deposits in the fuel oil heaters. Generally speaking, an unstable oil which gives tank deposits and sludges also will give heater deposits. The converse, however, does not necessarily hold.

(*c*) Combustion difficulties which usually are manifested by objectionable quantities of stack solids, ash deposits on the firesides of tubes and in the furnaces, excessive carbon deposits on atomizers, slagging of brickwork, and lowered combustion efficiencies.

(*d*) Pumping difficulties.

All of the above problems are being studied and the previously mentioned issue of this JOURNAL describes the scope of much of this work. At the present time it is possible, however, to discuss some of the factors involved and the more obvious remedies which will do much toward insuring prevention of any difficulties.

COMBUSTION OF CRACKED FUELS.

The cracking processes, in promoting the chemical changes which result in larger gasoline yields, also produce re-formation of some molecules and perhaps other changes in the residual oils remaining after cracking. These changes are such as to give the oil inherently slower burning qualities. At the same time there apparently are formed some molecules which highly resist burning under the ordinary conditions present in naval furnaces. This causes a larger amount of deposits on the firesides of the boilers and also produces annoying discharges from the stacks, which conveniently are called stack solids.

The slower burning characteristic of these oils is manifested by somewhat longer, lazier flames. Optimum burning conditions must be maintained in the furnace at all times in order to obtain the best combustion. This requires that atomization of the oil be perfect, that the best viscosity for atomization be used, and that excess air be kept at a minimum. It generally is impossible, even under these conditions, to effect complete combustion of a small percentage of oil particles which evidently are some of the complex reformed molecules. These molecules pass through the furnace with little or no burning and emerge as stack solids. These are not unlike the sinospheres encountered in powdered coal installations. These molecules might well be labeled "stubborn" molecules. Analysis of these stack solids has disclosed that they are almost entirely carbon and apparently of a nature similar to lampblack. In the laboratory it is possible to burn these solids in a combustion train, whereas, when ignited in the usual way in a high temperature furnace they will not burn unless a current of air or oxygen is provided. Combustion then is almost complete.

It has been found with previous oils that the best atomizing viscosity is 150 seconds Saybolt Universal. This figure holds for practically all cracked oils which have been examined to date. It has been found, however, that increasing the viscosity to 225 S.S.U. results in little, and in some cases no loss in overall efficiency. In a few cases, however, it has been found that this higher viscosity is slightly advantageous both as regards overall efficiency and reduction in the amount of stack solids or fly ash. It sometimes happens that the temperature corresponding to the optimum viscosity is

above the flash point of the oil. Burning the oil above the flash point will cause an apparent increase in the spray angle of the sprayer plate in use. This is caused either by gasification of the oil, which produces an outer envelope around the main spray, or, by more rapid burning in this outer zone, which causes an apparent expansion of the spray angle. This condition may cause flame impingement on the tubes or the brickwork. This usually will result in an increase in the amount of stack solids, as well as a decrease in the burning efficiency, principally because of an increase in the hydrocarbon losses and perhaps somewhat greater carbon losses. Any flame impingement will produce a lowered combustion efficiency, and in the case of cracked oils this is perhaps more marked than with other oils. Consequently, in such cases it is usually desirable to lower the atomizing temperature, thereby increasing the viscosity, so that atomization takes place below the flash point of the oil. An increase in viscosity from 150 S.S.U. to 225 S.S.U. will allow a decrease in temperature of approximately eighteen degrees, which will generally be sufficient. A desirable procedure would be to lower the oil temperature about five degrees at a time and operate at each step for a considerable period of time, such as eight hours or more, and note carefully all changes in conditions before proceeding to the next step. In this way it should be possible to determine the best atomizing temperature for each bunkering of oil.

Many ships use the Vroom diagram for determining the proper atomizing temperature. One of the characteristics of the cracked oils is that the viscosity characteristics have been changed as well as the gravity characteristics, but the change in gravity does not give the expected change in viscosity. Although these fuels are heavier than former fuels, their viscosities have not been affected adversely in the same degree as might be expected. This was shown by Mr. J. B. Terry in the May issue of this JOURNAL. It has also been found on plotting viscosity curves of these oils that they do not fall in line with the Vroom chart arm, and for this reason errors in determining the temperature corresponding to 150 S.S.U. are likely to occur. These are not serious, since adjustments can be made later when opportunities permit. Because of the fact that the viscosity characteristics of these oils are not in

line with those to be expected, it is necessary to obtain the viscosity of the oil at two temperatures and plot the line either on double logarithmic paper or on the Vroom chart. In this way the proper temperature for 150 S.S.U. can be determined. Figure 1* is a plot of four oils of this character on double logarithmic paper, showing as a heavy black line the Vroom arm in one position. It will be seen that in every case the viscosity curves of these oils (extended as dotted lines) either cross or lie to one side of the heavy black line. It should be remembered that these curves are only extended curves and are not true conditions. Actually the lower portions of these curves appear to curve off to the right to a greater extent than with previous oils. The extension of the straight line portion of the curve is simply to show the variations which will occur when using the Vroom diagram, unless the viscosities at two temperatures are used.

It was stated previously that all necessary factors in burning cracked oils must be maintained more accurately at the optimum than previously. As regards the atomizing temperature it is desirable that the oil be furnished to the atomizer tip at the proper viscosity. Most installations fail to effect this condition because the fuel oil manifold on the boiler front is generally devoid of heat insulation. Present specifications do not call for insulation on these lines, probably because it has been felt that this would increase resistance to the air flow to the burners. It is believed that this increase is insignificant, and the possible gain by effecting better viscosity conditions at each atomizer is warranted. Under present conditions in most ships, the only atomizer which receives oil at the proper temperature is the first atomizer on the line. Each succeeding unit receives oil at progressively decreasing temperatures, so that the oil to the last burner in the case of large boilers is probably at a temperature from twenty to forty degrees less than that in the first atomizer. This condition will be aggravated in cases where small or low capacity tips are in use and all burners on the boiler are being used, because the oil velocity through the lines will be low and the temperature drop correspondingly high. It is manifestly important to maintain the same conditions in each atomizer if any set optimum condition at all is to exist.

* Chart reproduced by permission of Simmons-Boardman Publishing Co., publishers of "Marine Engineering" and "Shipping Age."

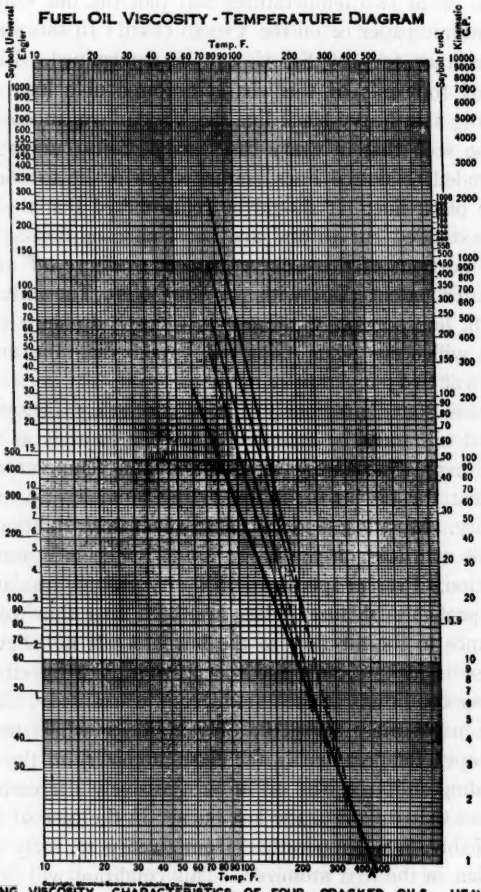


FIG. 1. SHOWING VISCOSITY CHARACTERISTICS OF FOUR CRACKED OILS. HEAVY LINE IS VROOM REFERENCE LINE.

Various methods of insulating the fuel oil manifold and even the branch connections in some installations is possible. There is available an asbestos cloth tape which can be wound spirally over these lines, and two thicknesses or even one thickness will improve conditions considerably. A half-inch layer of plastic insulating cement could also be used on the manifold lines. This would increase the resistance to air flow but little.

Most fuel oil burning equipment is so arranged that the character of the spray issuing from the tips is easily discernible. In order to insure that the atomizing equipment is functioning properly, it is necessary to give more attention to inspection of the sprays from all burners. Defective sprayer plates are spotted easily and should be removed as soon as found. It is believed that one defective sprayer plate in the case of these oils, although it might not produce smoke, could easily cause an untoward increase in the amount of stack solids. Careful inspection of the furnaces, using goggles, also will indicate defective burner equipment as well as other conditions which are conducive to poor economy and high stack solids. A liberal number of peepholes should be provided in every boiler so as to facilitate flame observations.

Excess air in the boiler naturally decreases the furnace temperature and shortens flame length. Both of these conditions are obviously inimical to good combustion of a relatively slow burning oil. Greater care therefore should be given to operating continuously with minimum air pressures and more attention should be given to making desirable though small changes in air pressure when minor changes in combustion rates are made. It is barely possible in the cases of oils which are notably slower in burning and which possess an unusual amount of the " stubborn " molecules that the trace smoke condition may not give the most efficient combustion. A slightly greater amount of excess air may improve the completeness of combustion and reduce the amount of stack solids, provided the excess air is not sufficient to lower the furnace temperature.

High combustion efficiency is intimately related with fineness of atomization. Fineness of atomization in turn is intimately related with the design of the oil burning equipment, the viscosity of the oil, and the pressure at which atomization occurs. It has been

found in numerous tests that fineness of atomization becomes increasingly poor at pressures below 225 pounds gauge. In the case of cracked oils this figure is more nearly 250 pounds gauge. For this reason the oil should be furnished to the atomizers at a pressure not less than 250 pounds, being sure to allow for the pressure drop between the gauge and the atomizer itself. The gauge should be located preferably at the dead end of the burner manifold. More frequent testing of gauges on the burner manifold is probably desirable in order to insure accurate pressure indications at all times.

The tendency of cracked oils to produce deposits on the ends of the atomizers and on impellers is much more pronounced than with straight run oils. It is believed that the conditions which adversely affect good combustion are conducive also to carbon building up on the ends of the burners. Frequent mechanical cleaning is necessary to remove these deposits. Efforts are being made to discover non-inflammable chemicals which will assist in cleaning atomizers.

Very little difference has been noted in the effect of these oils as compared with other oils on the slagging of furnace refractories or the amounts of carbon which build up in the furnace.

HEATER DEPOSITS.

The danger of fuel oil heater deposits is an ever present menace with these fuels. About two years ago on the occasion of first using cracked oils in naval vessels, a few instances of excessive heater fouling occurred. This was instrumental in delaying the final adoption of such fuels for general use.

Heater deposits can be said to be a function of the temperature to which the oils are heated. The higher the temperature the greater the possibility of forming deposits and the greater the amount of fouling. Operating conditions are such as to create many opportunities for excessive overheating of the oil, even though the personnel is quite vigilant in making heater adjustments. It now becomes of even greater importance to make heater steam adjustments more quickly and more accurately. Many temperature regulators or viscosity control devices have been tried

out in the past five years, and so far none have demonstrated the necessary attributes of continued accuracy and reliability.

A reduction to a minimum of the temperature differential between the heaters and the atomizers is highly desirable. The answer, of course, is effective heat insulation of the fuel oil heaters themselves (including especially the heads) and the fuel oil lines from the heaters to the boilers. Too often the insulation of fittings, valve bonnets, and pipe line flanges is neglected. These points now are deserving of attention. When operating under port conditions the oil velocity in the lines is so low that lack of insulation in these places, as well as those previously mentioned, might result in a heat loss which would require heating the oil in the heaters to a point which would result in deposits. The previous laxity in properly covering fuel oil heater heads and fuel oil lines should not be tolerated any longer.

The possibilities of trouble from heater fouling should focus attention also on heater design. Heaters should be so designed that they can be disassembled easily and quickly and so that the oil surfaces can be easily cleaned. Proper design also will insure not only a minimum fouling tendency but tolerance of considerable fouling before operation is affected seriously.

SLUDGE AND DEPOSITS IN OIL TANKS.

Very little trouble from tank sludges and deposits has been experienced with oils previously furnished. In the same way that possibilities of heater fouling have increased with the adoption of cracked oils, so also have the possibilities of troubles from formation of sludges and deposits in the storage tanks increased. The crying need at the present time is the development of a reliable short-time test which will enable determining whether or not an oil will be unstable in storage and thus enable preventing deliveries of such oils.

A cracked residuum of itself is generally stable in storage. When blended with more lightly cracked residuums and/or lighter gas oils or straight run residuums, there may be produced an unstable oil. Blending, of course, is resorted to in order to provide an oil of the specified viscosity characteristics and the required gravity.

In one case it was found that of two blends made up from the same two stocks, the one having the higher percentage of gas oil was unstable.

Instability in storage has been found to be largely a function of time. This is probably because in the blended oil there is a slow but gradual formation of polymers or complex high carbon, low hydrogen chains or compounds. The rate of formation is influenced no doubt also by an increase in temperature. The latter explains why most oils which are unstable in storage generally also form heater deposits at relatively low temperatures. It is probable that the apparently stable oils which give heater fouling are really slightly unstable, lacking only an excessive time element to demonstrate their instability.

The obvious procedure to insure freedom from storage troubles lies in preventing mixing or blending when bunkering, and reducing to a minimum the time of storage in any tank. The first can be accomplished by providing and requiring the use of suctions as low as possible in all tanks. Before bunkering, a tank should be emptied as completely as possible. Partially emptied tanks should be avoided, and where this is impracticable these remnants should be pumped into one tank. It is advisable also to use as soon as convenient the remnants so concentrated. In order to reduce the time of storage in any one tank, it is only necessary to develop a rotative schedule for using oil from the various tanks. This will require some ingenuity in the case of vessels having large numbers of small tanks. Subsequent bunkerings should not interrupt the rotative schedule, although it may require some slight changes. The plan of rotation of tanks naturally will require some flexibility.

It appears from a study of the oils examined to date that little difficulty will be experienced in pumping these oils from storage tanks. Provisions for heating in the storage tanks will be necessary always, but for the present it is not believed that these need be greater than heretofore. Proper design of these heaters is important also.

Several reports from merchant vessels have indicated that their troubles with cracked fuels are concerned largely with the prevention of excessive stack solids. In the case of large passenger liners,

this fly-ash is most objectionable. Merchant vessel boilers usually have much larger furnace volumes than naval boilers, so that the time interval for effecting combustion is greater. Providing the fraction cold is not too great, and other features of furnace design are correct, it should be possible to keep stack solids in merchant vessel installations at a minimum if proper care is taken in burning the oil.

In conclusion it may be stated that the burning of cracked fuel oils is attended with more difficulty than the burning of the previous straight run residues. These difficulties are not insurmountable and require mainly a better and closer maintenance of optimum furnace conditions. Continued investigation of the burning characteristics of these oils, improvement in burning and heating equipment, improvement in furnace design, and refinement of operating methods are all desirable.

A BRIEF DISCUSSION OF PRACTICAL APPLICATION OF METALS IN NAVAL MACHINERY DESIGN.

By COMMANDER C. S. GILLETTE, U. S. NAVY, MEMBER.

This paper attempts to cover a brief survey of the metallurgical field with emphasis placed upon the properties of metals as they affect the engineer rather than upon any purely metallurgical aspects of the subject. It is assumed at the beginning that a given item of mechanical equipment has been designed on a correct theoretical basis to produce efficiently and economically the results desired when properly constructed. It is further assumed that the metallurgist has done his work and that laboratory results giving the best available information on the characteristics of the metals which may be selected for use in such construction are at hand. It then remains to select the most suitable materials for the detail parts, to proportion and fit the parts together to produce a practical working whole, within the limitations of practicable economical manufacturing methods. This final step constitutes about 90 per cent of successful machinery design.

All machinery design is a compromise with the ideal. We cannot achieve perfection in any one characteristic except by sacrifice of some other desirable feature. The ideal final result in such a compromise would be, of course, that achieved by the designer and builder of the famous "one-hoss shay," which was justly celebrated in a poem by that name. In this perfect design all parts were so completely proportioned and coordinated one with the other that no single item failed in a long and useful life. Eventually, after a long and rigorous service, all parts failed simultaneously in a complete disintegration, thus bringing to an end the most perfectly balanced design in history.

In both land and marine practice, it is generally recognized that higher efficiencies are to be obtained from heat engines either by increasing the maximum temperature or lowering the minimum temperature. In the steam plant of today, higher pressures and

higher temperatures are the general order. And in all of this new departure the problem of materials is the controlling factor. In boilers, superheaters, engines or turbines the effect of temperature on the properties of the materials and the possibilities of internal changes taking place as a result of temperature and time, corrosion, and erosion are of fundamental importance. As the pressure is increased stresses tend to increase likewise. As the temperature increases beyond certain values the strength of most metals rapidly falls and development is distinctly limited by the possible temperatures which may be reached in practical operation.

For the machinery equipment of combatant vessels of the Navy every consideration is given, or should be given, to the primary requirement of reliability. Basically, a combatant vessel of the Navy is built for one purpose, and one purpose only, namely: to engage in combat with the enemy and to engage successfully. That is the one purpose that justifies the construction of combatant vessels.

The serious results that may be imagined following a vital material failure on a fighting unit of the Fleet in an actual naval conflict would seem to demand reliability of operation at any sacrifice of other qualities, but a fighting vessel must inflict damage to enemy vessels to the greatest possible extent and therefore its offensive armament must be balanced against its defensive characteristics within a tonnage limited by international agreement and within a space limited by practical ship design.

Thus we have the basic factors of light weight and minimum space requirements, second only to reliability in importance, which are, however, more or less directly opposed to reliability to the extent that this characteristic is sought, as is frequently the case, through generous weights and proportions of parts. Therein lies the principal difference between commercial design and naval design. And it is well to keep this always clearly in mind that whereas in commercial design of whatever nature the first consideration must be given always to operation at a minimum of original, operating and maintenance expense—and only on economical grounds can such a design be justified—in naval design, cost, original or operating, is not a measure of fighting qualities, except as economical use of fuel contributes to a strategical advantage in handling vessels in the theatre of war.

This, I think, answers the question so often asked as to why the Navy does not use in all details commercial standards of material and detail designs of specific items of equipment. A commercial concern makes money or it goes into the hands of a receiver. Combatant vessels of the Navy must fight successfully or go to the bottom of the sea.

Having stressed these primary characteristics, namely: maximum reliability and minimum weight and space factors, we may glance somewhat more casually at the other important considerations which affect a selection of metals for use in naval design. In order of importance these may be summarized as follows:

(*a*) *Maximum resistance to corrosion and erosion:* Erosion, whether or not it is linked with corrosion, is always present when liquids or gases travel at high velocity and by turbulent flow.

(*b*) *Maximum resistance to failure by shock or impact:* I think we can all agree that nothing except armor plate can absorb a direct hit from the enemy without more or less complete failure. We can, however, take measures to insure to the greatest possible extent that the impact of the discharge of our own guns, as well as the explosion of shells, torpedoes, bombs or mines of the enemy in the general vicinity of the machinery will not result in its partial or complete disablement.

(*c*) *Minimum cost:* While I have spoken previously and somewhat disparagingly of cost in regard to naval design, none the less it is extremely important that we produce and operate the most effective amount of fighting tonnage that the limited appropriations for the Navy will permit. So original costs and operating costs must be given full consideration in connection with any design, and we must be quite certain that increased cost is justified by increased fighting efficiency as represented by increase in reliability, or decreased weight or space requirements.

(*d*) *Maximum availability of the material within the industrial organizations of our own country:* This factor is important, but it has many ramifications. The main fighting force of our Navy is built in times of peace and, under such circumstances, this factor must be given some thought, particularly in regard to the replacements of items as a repair proposition, but it is not of paramount importance except as it may be related to cost as covered in item

(*c*) above. For construction after war is declared, however, the matter becomes of major importance as our supply of certain materials produced in other countries may then be cut off and suitable substitutions will be necessary.

Having outlined in the foregoing the general considerations governing the selection of metals for naval machinery design, let us examine next the more important information which the metallurgist, supplemented by the laboratory, can and does supply us with regard to the characteristics of the metals themselves. This information is usually given along the following lines, based almost exclusively on test samples which have, as nearly as may be practicable, passed through the same manufacturing processes as the metals represented have passed. But it must be kept in mind that a test sample is only a test sample and is only indicative and not absolute as a basis for determination of the characteristics to be expected in a finished product.

It is considered best to approach the field of metals in general with a consideration of the ferrous metals, as these are the fundamental basis for the design of all heat engines. The entire machinery industry has, from the earliest days, been based on the use of mild steel. From this point of departure developments for the improvement of reliability and efficiency of heat engines has followed directly the improvements in steel.

The following items of information are usually available to us in connection with any ferrous metal:

(*a*) Chemical analysis.
(*b*) Tensile strength, elastic limit, yield point and proof stress.
(*c*) Elongation.
(*d*) Reduction of area.
(*e*) Bend test results.
(*f*) Impact resistance.
(*g*) Hardness number.
(*h*) Heat resistance qualities.
(*i*) Corrosion and erosion resistance qualities.
(*j*) Resistance to galling or seizing.

Each of the foregoing will be discussed in regard to their improvements and in connection with their ramifications as briefly as practicable.

CHEMICAL ANALYSIS.

Chemical analysis in detail is not usually considered of vital importance in Navy specifications except as regards certain basic features. In the carbon steels these are classified first on the carbon content because it is upon the carbon content that the other physical characteristics of the steel depends. In the alloy steel, also, the carbon content is a fundamental characteristic and must be stated in any specification.

The next items of importance are the phosphorus and sulphur contents. These are usually stated as maximum limits for all steels. The primary reasons for limiting these two constituents are that excess sulphur causes hot shortness and excess phosphorus causes cold shortness. That is to say that sulphur lowers resistance to shock while the metal is hot and phosphorus lowers the resistance to shock when the metal is cold. In addition, these two elements tend to segregate and concentrate forming the non-metallic inclusions in the steel causing internal nuclei of weakness from which failure may start.

Other alloy elements which are introduced to improve the physical characteristics in one way or another must be stated frequently as minimum limits because these elements are usually items of expense and control the cost of the steel. In this class are considered those elements which produce increased hardness, toughness, higher corrosion and erosion resistance, heat resistance, etc., such as nickel, chromium, tungsten, molybdenum, vanadium, manganese, etc., and stabilizers such as titanium and columbian.

TENSILE STRENGTH.

The ultimate tensile strength is the mechanical value on which practically all Navy design is based. It has been and still is the general practice in the Navy to use the ultimate tensile strength of a material as the basis upon which to establish factors of safety in design. There is a growing tendency, however, to base new design on yield strength represented by "proof stress." The properties expressed by the terms "elastic limit" and "yield point" have not been used widely as basic factors in design in the past because of the uncertainty which frequently attaches to their

determination on the testing machine. But the properties expressed by "elastic limit" or "yield point" are in reality the properties which are, or should be, considered in design. So long as these properties bore a fixed relationship to the ultimate tensile strength, the latter could be used safely as a design factor. However, in modern steels of varied compositions this relationship no longer remains fixed. The stress at which permanent deformation of the material actually takes place is termed "proof stress" and is the most essential item of knowledge in connection with the material that the designer must have. I believe that future revisions of Navy Department specifications will be found more and more to require establishment of yield point by the proof stress method.

Under the heading of physical properties must come a consideration of the characteristics termed "endurance limit," "corrosion fatigue limit," and "creep limit" at elevated temperatures. The designer of all items of machinery must give consideration in his selection of materials to the kind of stress to which each item is subjected in service operation. Any moving part of machinery is usually subjected to alternating stresses. These stresses are usually within a definite range and frequency. We do not have to determine these stresses in each case as generally they are impossible of analysis, but we must take steps to determine the endurance limit of the material we desire to use and to be sure that the calculated stresses are well below the endurance limit which the laboratory has determined for the material in question.

Corrosion fatigue limits of a steel must be given full consideration if under operating conditions the metal is subjected to any corrosion medium while stressed. We know that the corrosion fatigue limit for most steels, other than those of corrosion resistant composition, which have a tendency to corrode in any medium is not a factor of the ultimate tensile strength as is the case for endurance limit or fatigue resistance in air. It may be stated, in general, that for any steel which has a tendency to corrode in the medium in which it operates will have a fixed maximum corrosion fatigue limit independent of its ultimate tensile strength. That is to say, an ultimate tensile strength above approximately 75,000 does not justify the assumption that the corrosion fatigue limit will be raised in accordance therewith. Thus, for example, we

cannot take advantage of higher tensile strength steels to permit the reduction in size of ships' shafting which always operates in a corroding medium while stressed.

It is generally recognized that the tensile strength of steels obtained by short time loading at temperatures above approximately 700 degrees F. is of little value as indicating the safe operating stresses at such temperatures. That is, steel in general above 700 degrees F. will have a tendency to creep under a tensile loading above a certain limit. So where steels are to operate under stress at elevated temperatures we must know the stress at which creep of a fixed quantity is likely to occur. The stress which produces a creep or extension under load of approximately 1/10 of one per cent in 10,000 hours while the material is held at a given temperature is considered as the maximum stress to which the material can safely be loaded in service at the specific temperature. The introduction of alloys is a definite controlling factor in the production of steels of high creep limits. In general it may be said that molybdenum is the element producing this desirable characteristic and this element is usually combined with chromium in steels to produce not only high creep limits but the added characteristic of resistance to surface oxidation and scaling at high temperatures. These alloys are introduced to raise the lower critical point.

ELONGATION.

Reasonable high elongation under tensile loading before rupture is considered an essential characteristic to establish that the steel is of normal quality. It is of great importance in a consideration of any material for use under vibratory loads.

REDUCTION OF AREA.

This characteristic is usually associated with elongation and is given consideration in connection therewith. High reduction of area is generally considered a very desirable characteristic. It serves more as an indication of crystal size than any other purpose.

BEND TESTS.

The bend test is necessary to indicate satisfactory ductility and proper anneal, especially for cast steel.

IMPACT RESISTANCE.

Impact resistance is of primary importance in a consideration of any part of mechanical design which is or may be subjected to shock under any condition of loading. Impact resistance at room temperatures and at any elevated temperatures to which the metal may be subjected under operating conditions is of the utmost importance. It is only recently that consideration has been given to impact resistance under tensile loading at various temperatures. Such a characteristic is seldom specified to date but its determination for any important or vital and highly stressed structural part is essential. Investigation along this line is rather a new field and is not fully covered to date. Impact values, in general, bear no relationship to other physical values.

HARDNESS NUMBER.

The surface hardness of any given material is a definite factor of design for parts which are subjected to wear or abrasion. This characteristic is closely allied with other physical characteristics of the steel already enumerated. In general it may be said that a determination of the hardness number is the best method of arriving quickly at a comparison of the characteristics of a metal as compared with any other of the same general composition. For wear and abrasion resistance special methods of surface hardening are resorted to in order to improve this characteristic of surface hardness without materially affecting the internal structure of the part, such as nitriding and case hardening. In obtaining a high degree of surface hardness we must usually accept a certain amount of brittleness but if we combine surface hardness with a tough core we have the best combination for practical uses under wear or abrasive conditions. Curiously, it has been pretty definitely established that hardness is not necessarily a desirable characteristic for resisting erosion.

HEAT RESISTANCE QUALITIES.

Heat resistance qualities have already been covered to a considerable extent under the heading "tensile strength" above. Full information must be obtained in connection with any metal

for high temperature service, not only as to the changes in the tensile strength, reduction of area and elongation at the elevated temperatures, but also in regard to the integrity of the surface, *viz.*, its tendency to remain stable under such temperatures. This latter particularly applies in such heat equipment as boilers and superheaters. In the design of the latter equipment the attempt is made by movement of the fluid on one side of the metal to prevent the metal temperature from becoming very much higher than that of the fluid, such as water or superheated steam. However, consideration must always be given to the fact that the metal walls do reach a temperature higher than that of the contained water or steam. These metal walls are exposed on one side to hot gases or to radiant heat and must of necessity be at a temperature higher than that of the fluid temperatures in contact with them. Definite information on this point is not available but in general it can be said that the actual metal temperature is approximately 100 degrees F. higher than the fluid or steam temperature to which the heat is being transmitted. In the resistance to surface oxidation due to high temperatures, chromium is probably the most satisfactory alloying element.

CORROSION AND EROSION RESISTANCE QUALITIES.

The resistance to corrosion which is so essential for practically all metals for ships' machinery construction has been obtained in the last few years in the ferrous metals by high percentage alloying with nickel or chromium, often both. The field of the various alloy steels in this class is quite vast and it is difficult to handle this subject briefly. Nothing is less exact in the engineering field than definite and dependable conclusions in regard to corrosion and erosion. We have years of practical experience to guide us and volumes of laboratory data, but the only positive criterion on which we can depend is actual service results and even these are uncertain if the conditions in any given installation change. We are confronted in the use of corrosion resisting steels with high cost and the results that we expect to obtain are definitely affected by heat treatment in most cases. Probably the most efficient combination now available in the corrosion resisting steels is the 18-8 combination, that is, 18 per cent chromium and 8 per cent nickel.

This steel is austenitic, and peculiarly susceptible to cold working whereby its tensile strength and surface hardness are increased remarkably. It is highly corrosion resistant and is used wherever corrosion and erosion resistance is of primary importance and where the peculiar characteristics of the metal can be utilized in a practical way.

RESISTANCE TO GALLING OR SEIZING.

This is a characteristic which must be given consideration in any application of metals working against each other especially at elevated temperatures, that is to say, at any temperature above about 750 degrees F. Specifically, let us consider steel nuts for use on main steam pipe line joints at high temperatures. It is practically certain that any material used for these nuts and bolts will seize at these high temperatures and be extremely difficult to disassemble. For this specific application we are now attempting to use a compound of special character (a mixture of graphite, red lead, and linseed oil, or graphite and kerosene) on the threads to prevent this. We are all familiar with the tendency of threads in aluminum, for example, to gall at any temperature. In general the Bureau requires that where threads are necessary in aluminum they should be put in steel inserts cast or tapped and threaded into the aluminum. Other metals have a tendency to gall badly when operating in contact under high pressure and if the operation of a specific item of machinery can be affected by this tendency, careful consideration must be given to the selection of metals for this purpose. Attempts are being made to accumulate more laboratory information on this matter at the present time.

The foregoing is a brief survey of the steels and the characteristics which affect selection for specific mechanical parts. For electrical purposes, other factors enter the picture to a limited extent such as magnetic permeability, etc. But, still further consideration must be given in connection with the practicability of production of the part in the form desired. Naturally, the greatest dependence can be and is placed on steel forgings, either used as such directly or machined or ground to the exact dimensions required. It can be stated without question that the greatest reli-

ability and the minimum weight and space can usually be achieved through the use of forgings properly selected, heat treated and machined to the finished dimensions. However, attention must be given to the selection of test samples to represent a forging in both the longitudinal and transverse directions in order to get a full understanding of the physical characteristics.

Next in importance from a fabrication standpoint is casting. We must resort to this method for much of our work. However, lightness of weight is often defeated in the use of this method because of the necessity of using walls thicker than the calculated stress demands in order to obtain sound castings.

Light steel castings have been developed to a limited extent and will, no doubt, be developed further. The necessity for research and development along this line is apparent universally. The greatest handicap in the use of steel castings for pressure and highly stressed work, in general, is the apparent inability of the steel manufacturers to produce sound castings in steel for the complicated and special castings required for naval design. Defective castings cannot readily be detected or, at least, not until extensive machine work on them has been done. The result is, of course, that we must usually resort to welding in correcting defects and must depend on non-destructive methods of test, such as the x–ray or the gamma ray to locate internal defects which the machining does not show up. Welding of defects where the work can be fully annealed as a final operation, thus relieving internal strains, and where the most practically satisfactory welding method, namely, the shielded metallic arc, is used, cannot be said to be unsatisfactory. However, it cannot be claimed to be as trustworthy as a thoroughly sound casting. In any case, practically every large and complicated steel casting and most of the ordinary ones on board ship today have more or less defects corrected by a welding operation. None are known to have failed due to this practice to date. However, many steel castings have been and will be rejected for extensive defects, resulting in expense and delays in ship construction.

Next in order of importance of the primary fabrication processes for handling steel is that of assembly by welding, using parts of rolled, forged or cast metal. This is a comparatively new de-

velopment, but of increasing importance as the art is improved. Essentially, when all is considered, it is a specialized casting method, for the metal deposited by the process is really cast steel. As such it should be annealed as a final operation but frequently, as in field assemblies, it never is. Further, welding is most frequently a manual operation and therefore subject to the personal equation and the finished work often does not lend itself to any known test method which will give positive assurance that the work has been properly accomplished, that is, that the weld is sound. As an automatic process, the results can be relied upon more completely in direct proportion as the personal equation can be eliminated. In cases where the finished work can be inspected by a satisfactory non-destructive test method such as the x-ray or gamma ray, then still greater assurance of reliability is possible, such as for example that which substantiates the Bureau of Engineering's approval of this method for high pressure boiler drums. But, despite all argument to the contrary, it is still this writer's opinion that a pressure vessel without a seam is better than one with a seam. But, as in boiler drums, a seamless forged design often results in excessive cost without commensurate gain in reliability. In general, never place positive reliance in any form of welding of a vital machinery part unless the welder who does the work is highly experienced and reliable, the method and welding rod are the best that can be obtained, and the weld and surrounding metal are thoroughly annealed as a finishing operation, and even then warping of the work may result from the welding or annealing operation which will prevent the use of the part for the purpose intended.

If and when, the use of high temperatures demands the use of alloy steels, then welding faces a more serious situation. In general, it is accepted that carbon steels with a carbon content in excess of 0.35 per cent should not be joined by strength welds of any character. Each and every alloying element in steel requires specific investigation as to the resulting weldability of the resulting alloy.

Still further complication regarding weldability is introduced if the physical characteristics demanded for the application of an alloy steel require special heat treatment to produce them. The

welding operation upsets the heat treatment and every step of such treatment must be carefully repeated after any welding operation or the desired physical characteristics will not be obtained.

Other fabrication methods of rolling, die forging, drawing, extruding, etc.—all have their place in industry, but time will not permit discussing these at the present time.

Next in order of importance of the ferrous metals the subject of our old friendly enemy, cast iron, must, though reluctantly, be taken up. This metal ranges today from the lowest grade cast iron of window weight quality up through the semi-steels and alloy castings of high tensile strength. Many improvements in cast iron have been made in recent years such as (1) Reduction in porosity and tendency to growth, (2) Grain refinement, (3) Wear resistance, (4) Machinability, (5) Increase of ductility at normal temperatures and (6) Increased tensile strength and resistance to corrosion at high temperatures.

However, for use on fighting ships for vital stressed parts it still remains pretty much cast iron with its lack of elongation, low impact resistance, its tendency to grain growth at elevated temperatures, and the difficulty of repairing defects or failures by the usual repair agencies such as welding. The foregoing deficiencies together with its weight should and do prohibit the extensive use of cast iron on combatant vessels. However, there are, of course, many minor applications where its use is desirable and even necessary, such as for rubbing surfaces in general, piston rings, bushings, etc. The ease with which sound castings are made and the cheapness of the material in general, compared with the difficulty and expense of steel castings, forces cast iron upon us for various applications against our better judgment. Let us consider one of the most annoying problems connected with its use, *viz.*, turbine casings and gear casings. Such castings are nearly always large, complicated and expensive and the designer frequently does not or cannot give the necessary attention to the demands of the foundry in laying out his design to insure the production of sound steel castings. The result is defective steel castings, rejections, expense, delays and, in desperation cast iron is often resorted to as a substitute for steel for this important application. True, except for weight, it is usually quite satisfactory and its service life in peace

times often leaves nothing to be desired. But can we depend upon it in the shock of battle? Little exact information is available but mature judgment would, I feel sure, decide against it. And, if it fails, repair can be normally accomplished through replacement only. The trend is, therefore, away from this questionable material for the more important applications and toward light, sound castings in steel, or welded assemblies of steel parts consisting of simple steel castings and structural shapes.

To date little has been done in the use of castings in corrosion resisting steel, but with the use of steam temperatures around 900 degrees F. we find much use for the alloys of manganese, chromium and molybdenum to reduce tendency to the creep of stressed parts at high temperatures.

I think now we can leave the field of ferrous metals and turn very briefly to the almost unlimited field of the non-ferrous. The briefest sort of survey only is possible with special reference to the metals most commonly used in the naval service.

The use of non-ferrous metals, in general, is dictated by three primary considerations, *viz.*, (1) Resistance to corrosion and erosion, (2) Reduction in weight for lightly stressed or non-stressed structural parts, and (3) Bearing metals.

The most important class is, of course, the copper-zinc alloys, and the copper-tin-zinc mixtures. These are excellent alloys and used extensively at normal temperatures. The high tensile alloys such as manganese bronze, and aluminum bronze are extensively used for propellers and other highly stressed parts subject to corrosion by sea water. The lower tensile alloys such as the bronzes known as compositions G and M, admiralty metal, etc., figure largely in castings for sea water resistance and for condenser tubing and similar applications. These are limited in use to temperatures not exceeding 425 degrees F., for their strength is rapidly lost at higher temperatures.

The next important series is that of the copper-nickel compositions giving high tensile strength, high resistance to corrosion and erosion and satisfactory for use at elevated temperatures. These are often being replaced today by the corrosion resisting steels such as in turbine blading and valve trim.

The bearing metals need little comment. These are usually of tin-lead-antimony combinations, or, for exceptionally high demand work, of the copper-lead combination. Our principal consideration is to maintain the highest quality consistent with ready renewal by ordinary facilities found on board ship.

The light weight and corrosion resistant demand is satisfied to a large extent by use of the various aluminum alloys for lightly stressed or unstressed parts. These, perhaps, are worthy of a more detailed discussion. Lack of satisfactory corrosion resistance in aluminum and its alloys has previously operated against its extensive use for marine work. Today we have many high tensile alloys of sufficient corrosion resistance for our purposes. Other deficiencies in these materials can be and are taken care of by giving thought to the design. In these, as with many other alloys, electrolytic interaction between aluminum and other metals used in combination with it must be guarded against constantly. Screw threads in aluminum must be avoided if parts must be disassembled. And, above all, we must remember that all aluminum alloys are seriously affected by an alkali and avoid this in any practical application.

In design the light weight of aluminum cannot always be realized for stressed parts due to its lower tensile strength, its low modulus of elasticity and its loss of strength at elevated temperatures. In electrical work its conductivity is lower than copper but still considerable gain can be and is achieved in reduction of weight by its application for bus bars.

In general we can say of aluminum alloys that alloying with copper increases the tensile strength but decreases the corrosion resistance. The familiar alloy, duralumin can be cold worked, drawn, rolled and forged successfully and can, in the heat treated condition, give us the tensile strength of mild steel. The silicon alloys are of fair strength in the cast form and easily produced and have relatively, the highest corrosion resistance characteristics. The fatigue resistance of aluminum is low and for alternating stresses over a reasonably high range its use for such purposes is not wise.

Each and every application of non-ferrous alloys must be given careful thought in the selection of the proper material to be certain

that the really basic demand has been met. This is best illustrated by a practical example. In the selection of a material suitable for anchor bolts to hold the refractory brick in place in a modern naval oil fired boiler the primary considerations would seem to be (*a*) resistance to surface oxidation and scaling at the high temperatures encountered, and (*b*) sufficient tensile strength at such temperatures to hold the brick in place. These requirements must be met, it is true, but many combinations of metals which met them did not prove satisfactory as anchor bolts. Eventually, it was found that a still more important requirement was that the material of the bolts must not slag with the silicon of the brick at elevated temperatures. The material at present used meets all requirements and is reasonably satisfactory.

Again it was recently decided to take advantage of the corrosion resistant qualities of the so-called 18 and 8 corrosion resisting steel for machine screws in electrical fittings of cast aluminum to replace the cadmiun plated carbon steel screws which were not wholly satisfactory. But it was found that the 18 and 8 corosion resisting steel was an exceedingly bad combination, with cast aluminum from an electrolytic corrosion standpoint and the attempted modification was abandoned.

We profit by mistakes in that we gain experience in what not to do, often as important as to know what to do. An illustration is the attempt recently made in the Navy and elsewhere to use nitralloy for high pressure and temperature steel valve disks and seats. In spite of the extreme surface hardness of nitrided material, serious erosion occured in the seats of valves, especially those subjected to throttling service with superheated steam. This material has now been abandoned by the Navy, though commercially, when the nitriding is properly controlled, it seems to be giving satisfaction. It is not practicable to cover more within the scope of this paper, but it is hoped that enough has been said to center attention on the importance of giving the most careful thought to the selection of metals in machine design, if successful results are to be expected.

ELECTRICAL DISTRIBUTION SYSTEM ANALYSIS.

By E. F. Seaman.*

The interim between the design of the older naval vessels and the newer ships of today has been marked by the introduction of electrical equipment and its increasing use from year to year; more specifically this may be called a period of electrification. Coincident with and as a part of the increased use of electrical applications the electrical distribution cable system has grown to the point where a total of approximately 90 tons of cable is needed for installation on a cruiser of the *Indianapolis* class. In the design of each new group of ships considerable effort is expended so as to produce the most efficient and reliable system of operation. As a consequence the question arises as to whether future development should represent an expansion of the present system or whether certain changes would be productive of an arrangement more adapted to changing operating conditions. The answer to this is found in the analyses of the fundamental schemes around which the ship wiring can be developed.

Distribution layouts can be divided into two general types which, in their commercial application have been designated the radial and ring systems. These terms, when considered in connection with their elementary diagrams, Figure 1 and Figure 2, are self explanatory. It should be noted that centralized and decentralized generator installations are inherent characteristics respectively of radial and ring systems. It can be generally stated that all systems at their inception should originate with a radial layout where a central position is selected for the generating plant from which power feeders emanate to the loads in all parts of the ship. As the load density increases the number of feeders must increase so that at some point it would appear practical to establish a continuous ring bus of high current carrying capacity with feeders connected thereto throughout the length of the ship. When this step is taken the system has evolved from a radial to a ring design, and it is the study of such a change that forms the basis of this discussion.

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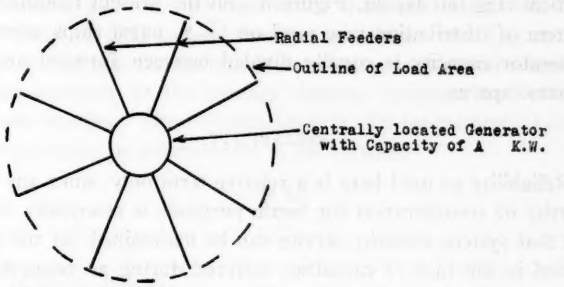

Figure 1.

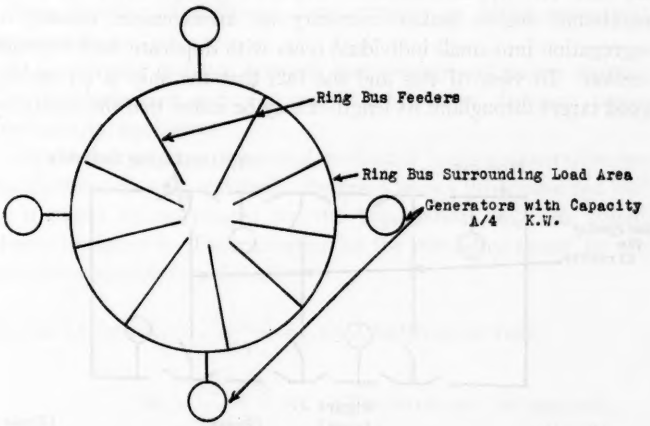

Figure 2.

While a decision leading to the adoption of any particular distribution system must necessarily be governed by facts ascertained in connection with a specific installation, it is true that the general aspects of the situation can be presented by reference to data available from past designs and its conformity to the principles limiting naval design, which in this case are:

(1) Reliability
(2) Economy of Weight and Space
(3) Operating Efficiency.

The advantages and disadvantages of the different methods of cable arrangement will be considered with reference to the hypo-

thetical ring bus layout, Figure 3, and the present modified radial system of distribution now used on U. S. naval ships where total generator capacity is equally divided between forward and after dynamo spaces.

RELIABILITY.

Reliability as used here is a relative term only, since any design worthy of consideration for battle purposes is essentially reliable; but that system whereby service can be maintained for the longest period in the face of casualties suffered during an engagement is the most effective and reliable. The accomplishment of this in the maximum degree makes necessary an arrangement capable of segregation into small individual units with duplicate feed for each section. In view of this and the fact that the ship is an equally good target throughout its length it may be stated that the reliability

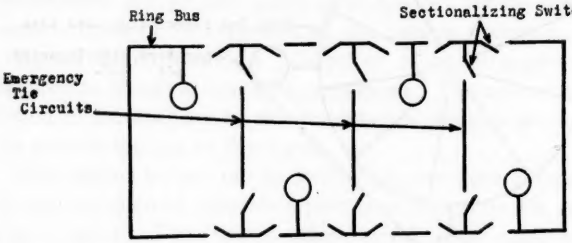

Figure 3.

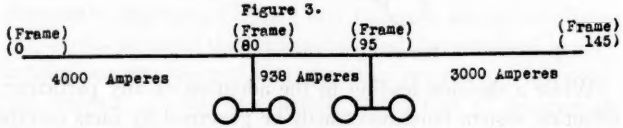

Figure 4

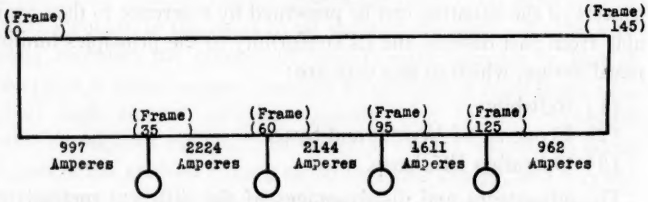

Figure 5.

varies directly as: (1) the number of duplicate feeds over different routes to vital current consuming devices, and (2) as the number of different compartments in which generators are located. It varies inversely as the average distance between load centers and power sources. These statements may, for the purpose of comparative analysis, be incorporated in the formula:

$$R = \frac{N\,C}{D}$$

Where:

R = Reliability factor.

N = Number of different compartments in which generators are located.

D = Average distance between load centers and power sources.

C = Number of different supply cables over different routes feeding vital appliances.

Figure 4 represents the actual connected load concentration for the *Portland* as now installed. Figure 5 shows this connected load as it might be rearranged for the hypothetical ring bus system shown in figure 3. Determination of the reliability factor for the two arrangements is as follows:

Radial System $R_1 = \frac{2 \times 2}{15} = .26$ Amidships section.

$R_2 = \frac{2 \times 2}{130} = .03$ Forward and Aft sections.

Ring System $= R_3 = \frac{4 \times 2}{70} = .2$ For all sections of Ship.

The comparative reliability factors of the two systems as estimated above is of particular importance when the forward and after locations of the turrets are considered.

One factor, mechanical rather than electrical, serves to nullify to a great extent the evidence favoring a decentralized ring system. Steam piping to turbo generators variously located as indicated in Figure 5 might suffer a casualty as well as interconnecting feeder cables. Hence the reliability noted for the ring system would be applicable only where short steam supply piping is used or

where a Diesel engine installation is practical. With the rapid development of the Diesel engine this may be a near future possibility.

Theoretically reliability could be increased to an unlimited degree by manipulation of the factors of which it is comprised, but practically it is restricted by the necessity for economy in weight and space.

WEIGHT AND SPACE.

The weights making up the cable installation consist of the actual copper required to obtain current carrying capacity, cable insulation and armor, stuffing tubes, and miscellaneous cable fittings. As cable sizes increase the proportional weight of copper with respect to insulation, armor and fittings also increases thereby resulting in less unit weight per ampere distributed. An example will serve to clarify this statement.

Assume that various loads are to be transmitted a distance of 150 feet. It is proposed to use for the first method of supply individual feeders for each 20 ampere (5 horsepower) load. It will be

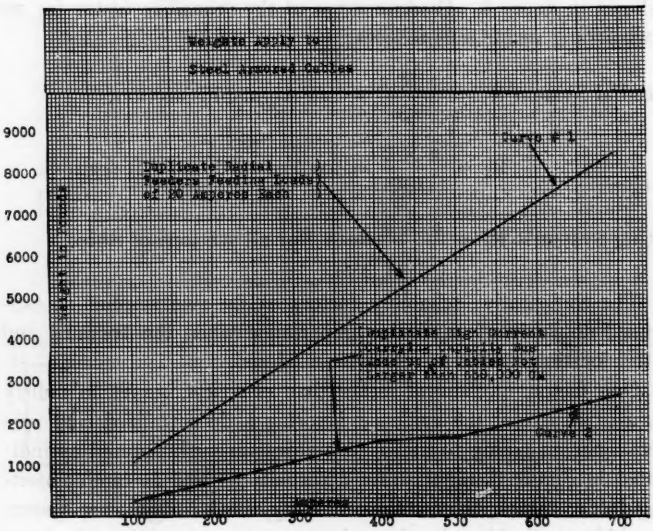

Figure 6.

assumed that all cables feed vital auxiliaries and that duplicate feed is necessary for each load so as to insure continuity of service. As a second method the ring bus will be used. The comparative weights are shown by curves 1 and 2, Figure 6. This example illustrates the general principle that for the two systems equal in reliability, as created by duplicate feed, the ring system is the more desirable because of its weight economy. The same saving is true with reference to space since a large number of small cables and stuffing tubes requires more space for installation than a fewer number of larger size.

If the trend of electrical load densities is to increase for future installations the weight and space saving possible through a main bus arrangement is emphasized in importance. It is believed that the saturation point for electrical applications is still in the future, which fact appears to be borne out by a study of the progressive increase in installed generator capacity as illustrated in Table 1.

TABLE I

Ship	Contract Date	Tonnage	K.W. Generator Capacity	Watts Per Ton	
Pittsburgh	1901	13,000	500	38.5	
Pensacola	1925	10,000	1000	100	Cruisers
Quincy	1933	10,000	1400	140	
McCall	1908	650	20	30.7	
Mason	1918	1,300	50	38.4	Destroyers
Dewey	1932	1,500	260	173.3	

SYSTEM EFFICIENCY.

Overall or system efficiency is determined from operation of the units making up the total electrical installation, such as generators, cables, and current consuming devices, which are designed primarily for effective performance during battle condition. They must at the same time meet the requirements of economical operation over the period of years that make up the normal life of the vessel. System efficiency can therefore be called the resultant of a battle efficiency and normal operating efficiency.

The essential relation between system efficiency and the battle condition is that of simplicity and quick performance of all operating functions. Where switching operations necessitate communication with a central point initial efficiency is high but after damage to a portion of interconnecting cable it is necessary and desirable to have a layout designed for operation in individual and independent sections with each power and lighting distribution switchboard panel in the vicinity of the load which it feeds. It would be possible to realize this through the use of a radial system modified to the extent that switchboard panels located at load centers and fed by bus feeders, were used, instead of central forward and after distribution boards. The ring bus system is particularly adapted to the segregation of the ship into sections.

The normal long time operating efficiency is important in that it determines the amount of money that must be expended yearly for maintenance. The features to be checked in order to insure efficiency in operation are the following.

(*a*) A uniform voltage is desirable at all points on the distribution system. Practically it is not possible to obtain strict uniformity, but with a ring bus system of distribution surrounding the load area it should be possible to reduce the difference in voltage drops by a large percentage. As a direct result of this, over voltage on lamps would be cut down and replacement costs due to burnouts greatly reduced.

(*b*) The use of larger and fewer cables will decrease cable replacement and painting costs.

(*c*) The elimination of grounds is favored by a reduction in the number of cables used.

(*d*) The actual cost of generating and delivering power to the point where it is utilized is dependent: firstly, on cost per kilowatt at the generator, and secondly, on I^2R or copper losses in the distribution system. Generating losses are a minimum when the generators are operated at full load and when they are in close proximity to the loads. At those times when one generator can supply the ship it is more economical to operate in this manner than it is to divide the load among several generators so as to decrease copper losses. Reference to the operation of recent cruiser generating sets will illustrate this point.

The sets in question are turbo-generators with water rates of 18.1 and 21.0 pounds of steam per kilowatt per hour for full load and one-half load respectively. At a cost of $0.000275 per pound to generate steam the difference in cost of continuous operation of the generators for a one-year period at full and one-half load is: (365) (24) (.000275) (250) (21 — 18.1) = $1747. The cost for each kilowatt copper loss at the one-half load rate is: (365) (24) (.000275) (1) (21) = $50.

To justify the operation of 2 one-half loaded generators in lieu of one fully loaded generator would, in this instance, necessitate a reduction in copper losses of 35 kilowatts. Such a saving is impractical.

In view of the above it is desirable at light load periods to have the generators located at the load center of the ship such as is the case with a centralized generator installation or for a decentralized installation with one generator so located. It is also obvious that for heavy load periods requiring the operation of more than one generator the greatest economical efficiency can be obtained through a decentralized generator installation, where a saving is effected by decreased copper losses.

SUMMARY.

The determining factors relevant to the design of an electrical warship distribution system have been outlined in general. Application of the general method of analysis to a specific case will result in conclusions influenced by the class of ship under consideration, treaty limitations on weight, load densities, and the type of prime movers proposed for the generators.

The evidence as herein presented and summarized in Table II is definitely in favor of a ring system of distribution, where the design of such a system incorporates all the factors necessary for its ultimate success. However, the necessity of using turbo-generator sets apparently precludes, for reasons of reliability and weight, the use of a decentralized ring system at the present time and points to a modified ring system with a centralized generating plant.

A modified radial system of distribution has proven satisfactory in the past. If, after a study of the data compiled for any

Table II

Advantages Desired	Advantages Obtained by				
	Generator Installation		Cable System		
	De-centralized	Centralized	Ring	Radial	Radial Busses to Load Centers
Reliability through close proximity of generating source and current consuming device using generators other than turbine driven.	x		x	x	x
Turbo-generator grouping to conserve maximum weight and space and obtain greatest amount of reliability.		x			
Reliability through duplicate feeders at greatest saving in weight and space			x		
Greatest battle efficiency by segregation of ship into independent sections.	x		x		
Uniform voltage throughout the system	x		x		**
Reduction in cable maintenance and replacement costs through larger and fewer cables			x		x
Reduction in ground faults			x		x
Maximum system economy when more than one generator must be run to supply load.	x		x		
Maximum system economy when one generator must be run to supply load.	*	x	*		**

x Applicable

* Applies when one generator is located at load center of ship.

** Applies if duplicate busses are operated in parallel.

ship, it appears advantageous to change to a ring system of distribution, such a change is neither impractical nor untried, since it has been successfully employed by the British Navy.

FOLLOW-UP SYSTEMS, AN ELEMENTARY DISCUSSION.

By Lieutenant Commander Herbert M. Scull, U. S. Navy.

A follow-up system may be defined as a mechanism by means of which the controls of a power unit driving an appliance are actuated so that the appliance follows the movement of a relative feeble controlling force. Two well-known examples are: The steering follow-up, which actuates the controls of the steering engine so that the rudder follows the helmsman's movement of the steering wheel; the gyro compass follow-up, which actuates the control of the follow-up (azimuth) motor so that the repeater transmitters remain in alignment with the sensitive element.

A follow-up system may be regarded as a mechanical amplifier system. Its function is analogous to the vacuum tube amplifier: The follow-up system has an input of varying mechanical position force, an output of greater mechanical force with the same variations in position; the amplifier has an electrical input of varying current or EMF and an output of greater current or EMF with the same variations.

In the design of a follow-up system several interrelated factors must be taken into consideration. Off hand, it would seem that sensitivity and accuracy could be improved by increasing the effective leverage of the controlling unit, so that smaller movement would serve to actuate the power unit. Also, it would seem that in the case of a follow-up system employing vacuum tubes, an increase in the amplification would improve sensitivity and accuracy. These are distinctly false assumptions; it is quite probable that if the system was reasonably well designed in the first place, a change of this kind will result in instability and inaccuracy. The succeeding paragraphs endeavor to discuss the relationship between the factors which govern the performance of follow-up systems.

Follow-up system errors fall into three general classes, dead space, speed lag and acceleration lag. When the controlled and controlling units are in exact agreement, there must be some movement of the control unit before there can be any movement of the controlled unit. In the case of mechanical follow-up systems controlling a fluid operated power unit, there must be enough displacement of the control unit to take up the slack of the various linkages, gears, etc., and move the throttle or pilot valve a linear distance in excess of the valve lap, admitting the fluid to the proper cylinders. The valve opening must cause enough pressure differential to overcome the static friction of the appliance. Electrical follow-ups usually depend on a balanced electric circuit, and the control unit must disturb the balance enough to cause the motor or relay to operate. The amount of this minimum displacement to produce motion can be expressed in terms appropriate to the mechanism, inches, degrees, etc., and is the "dead space."

When the control mechanism is moving at a constant rate in one direction, there will be a definite displacement (lag) which will be necessary to cause the follow-up to open the valve or unbalance the electric circuit the amount required to produce the force for that rate of movement. For examples: A movement of 10 degrees on a steering wheel opens the steering engine throttle valve ¼ inch. That amount of valve opening admits steam adequate to turn the rudder at 1 degree per second. Then when the helmsman turns the steering wheel at a rate corresponding to 1 degree per second movement of the rudder, the rudder will lag behind the steering wheel by an amount corresponding to 10 degree movement of the steering wheel. This will require large power units, which may be expected to have correspondingly large inertia.

If the control unit is in accelerated motion, the power unit must provide the accelerating force, as well as that required for steady motion, and there will be an additional displacement and lag. This is the "acceleration lag." To reduce this lag, the force exerted by the power unit, per unit displacement of the control, must be large; similar conditions to those for reducing the speed lag. However, as the size of the power unit increases, its inertia and force required for its own acceleration increase. For this reason, the acceleration lag is hard to reduce.

While the follow-up is in motion, the rate of motion of the power unit in most cases will be a function of the amount of displacement of the control. When motion of the control ceases, the power of the power unit is not cut off until it enters the dead space. Its momentum will cause motion to continue and it may overrun the dead space so that the control will give it the proper impulse in the opposite direction, causing hunting. This hunting will then continue until damped out by unavoidable friction or by designed damping means.

The perfect follow-up would have—

Zero dead space.

No hunt.

No steady motion lag.

No acceleration lag.

Attainment of all these desiderata is virtually impossible, but they can be closely approached. If the dead space is reduced to zero, hunting is a certainty, the momentum cannot fail to carry over a zero dead space. If the power unit is made very active and snappy to reduce the lags with large forces produced by small movement of the control, the inertia of the system is increased, further increasing the tendency to hunt. Also, in any system, there will be a maximum rate of speed and acceleration which the operating conditions require and of which the system must be capable. This requirement alone may force the use of such a large power unit as to render hunting probable or difficult to prevent.

Resuming the comparison of a follow-up system with a vacuum tube amplifier, similar effects may be present in the amplifier. As the vacuum tube circuit is adjusted for greater sensitivity, the tendency toward oscillation increases. Oscillation is similar to the hunt of the follow-up system, both being conditions of instability. A dead space exists in the amplifier, being the range of input signal which produces an output signal too weak to be usable. While the lag has been spoken of above in terms of displacement, each of them could be translated to time. For example, a lag of 1 degree during a motion at the rate of 10 degrees per second, is a 1/10 second lag. A time lag exists in the vacuum tube circuit. It is true it is so small that it is of interest more from the theoretical scientist than the engineer's, but nevertheless it does exist.

Employing an electrical method of "pick-up" of the motion of a control unit, it is possible with an amplifier to get a satisfactory control of the power unit with a linear motion of less than .001 inch. Essential clearances and elasticity of parts of any mechanical system render such sensitivity virtually impossible. Therefore, if a vacuum tube amplifier system can be employed in a follow-up system, the sensitivity should be improved and it should be possible to approach the ideal characteristics more closely.

The follow-up systems of the older gyro compasses are a somewhat special case. In these compasses, there is but one value for force of the power unit; any displacement of the control from the dead space produces the same force. In order to prevent excessive lag during high speed turns, this one speed of the follow-up motor must be equal to the maximum rate at which it is expected that the ship will turn. This makes the motor so snappy that on a steady course or while turning slowly, hunting is inevitable. The follow-up mechanism for steering some torpedoes is of the same type and characteristics.

Hunting may not be seriously objectionable in all cases so-called. Anti-hunt devices of various kinds can be introduced into the system, causing the final output to be the mean of the position of the hunting member. However, this type of anti-hunt device is essentially an averaging instrument and will have some error in itself. This error will usually be a lag when the system is in motion with little or no error when the system is at rest.

Follow-up systems would be more accurate and sensitive, without hunting, if they could anticipate the next motion of the control unit. That is, when the system has been in motion and is slowing down, the power unit would have a smaller output than for steady motion at the same speed so that when the neutral position were reached, the power unit would not overrun. Similar but reversed action would take place during acceleration. This anticipation would reduce the acceleration error, which is the most difficult to control. Such true anti-hunt devices have been made, at the expense of some complication, and present development is principally along this line, together with further extensions of the vacuum tube amplifier, keeping the follow-up in the electrical form as much as possible.

The general principles of follow-up systems also apply to other appliances. Governors, pressure regulators, voltage regulators, and reducing valves have similar characteristics. They will have a certain minimum displacement of the voltage, speed, pressure, necessary to actuate the device; they will have a lag in voltage, speed, pressure, at different loads and different rates of change of load. The same methods of reducing these errors that are applied to follow-up systems can be and have been applied to these machines when greater accuracy of control became necessary.

DISCUSSION.

EVOLUTION OF THE ARCRONOGRAPH.

By Lieutenant Commander G. C. Manning (CC), U. S. N.

Mr. Ronay's article cannot help being of intense interest to anyone who has had any work in connection with the development of electric arc welding of steel. His research has at last definitely answered the question as to why better welds can be obtained by heavily covered electrodes than by bare or washed electrodes. By a better weld is meant a stronger and more ductile weld. It has long been felt that the brittleness of the welds obtained from bare electrodes was due to the formation of iron nitrides during the welding process, which in turn was due to the absorption of atmospheric nitrogen by the fluid steel at the time of welding. This belief finds at least partial basis in the fact, that weld metal deposited by bare electrodes practically always shows higher nitrogen content than that deposited by good quality heavily covered electrodes. One explanation for the mechanics of the prevention of nitrogen absorption by heavily covered electrodes has been that the decomposition of the covering by the heat of the electric arc produces an atmosphere which "shields" the molten drop of steel from the surrounding air, thereby preventing absorption of atmospheric nitrogen. But all coverings do not act the same. Some indeed produce weld metal no better than if the electrodes were bare, even though they burn and produce smoke or other gaseous envelope for the molten drop of metal from the electrode.

Mr. Ronay's observations reconcile all previous data on the subject and thus offer the most logical explanation of the superiority of the heavily covered electrode; *viz.* that the drop of molten steel formed thereon is exposed to the surrounding air a shorter period of time and therefore has less opportunity to absorb nitrogen. The formation of the drop consumes a larger percentage of the cycle of drop deposition in heavily covered electrodes than in bare ones.

And conversely the time required for detaching and projecting the drop onto the base metal is less in heavily covered electrodes than with bare ones. The absorption of nitrogen must occur mostly after the drop has been formed. Therefore, the higher the arcronograph rating, the less nitrogen should be in the weld metal, and consequently the stronger and more ductile the weld. For reduced to its lowest terms, the arcronograph rating of an electrode is simply the percentage of the time of the drop forming period to that of the entire cycle of drop deposition.

There is one point in connection with the arcronograph rating of electrodes that does not appear concordant with other known facts, and that is, that in Figures 2 and 3, the arcronograph rating increases with increased carbon content of the electrode. The effect of carbon in steel is to lower the melting temperature. It would seem logical that an electrode of higher melting point would require a larger percentage of the drop deposition cycle for drop formation than one of lower melting temperature, since, in general, in the former case, the heat absorption required for drop formation would be greater than in the latter. However, the carbon contents of all electrodes included in the curves given in Figures 2 and 3, are very small and carbon content therefore has only trivial influence on their melting temperatures. The differences in arcronograph rating may be due to some other causes and the co-relation with carbon content may be purely accidental. It would be interesting to have Mr. Ronay's comment on this point.

The sweeping claims for the arcronograph made by Mr. Ronay on pages 295 and 296 would stand on firmer ground if information were given of the number of tests made to determine the optimum time-ratio for a given electrode and that associated with a definite carbon content of electrodes. The curves of arcronograph ratings given in Figures 2 and 3 appear to be straight lines. When a large number of observations are plotted, all of the plots seldom fall in a straight line. It is reasonable to assume that the curves of arcronograph ratings shown in Figures 2 and 3 are therefore obtained by averaging results of a large number of observations or of drawing the best representative curve to fit the results of the individual observations as plotted. It would be interesting to have more information on this point, particularly a reproduction of some of

the original plotting sheets showing the exact spots represented by the individual observations and how well the arcronograph curves of Figures 2 and 3 fit these spots.

In the three examples discussed on pages 296 and 297 and shown in Figures 7, 8 and 9, there is complete agreement between the arcronograph records, x-ray photographs and broken welds. Is it to be inferred that in all tests there was complete agreement between the true structure of the weld as shown by opening it up for visual examination and the arcronograph record of the weld? It is seldom in experimental work that one hundred per cent agreement is obtained. If the arcronograph gives even almost complete agreement with the actual conditions of the weld, it is a wonderful instrument and fills a long-felt want. Even if it is only say ninety per cent accurate, it is way ahead of visual surface examination. It would be interesting to hear from Mr. Ronay, the percentage of agreement between the actual structure of the welds and the arcronograph records which was obtained in the tests conducted during his research and after the development of the arcronograph.

DISCUSSION.

EVOLUTION OF THE ARCRONOGRAPH.

REPLY BY BELA RONAY.*

The following answers are submitted to the questions raised by Lieutenant Commander Manning in regard to certain statements contained in subject paper:

Analyzing Lieutenant Commander Manning's able discussion it appears that there are three points contained therein that require more detailed information than was possible to include in the paper published in the last issue of the JOURNAL. The three points are as follows:

(1) The influence of the carbon content on electrode performance.

(2) Relationship between carbon content and arcronograph ratings.

(3) Agreement between arcronograph records and weld efficiency.

In the following it will be attempted to answer the above questions, in the order given, within the space limitations.

(1) The difference between the performance of mild steel welding electrodes of dissimilar carbon content is not based on the variance of their melting point, which is undoubtedly within a too narrow range to be of any importance. The difference exists on account of the varying melting rate of electrodes of various carbon content and on account of the correspondingly varying degree of viscosity of the molten metal.

The welding rate of electrodes is determined from the formula $W = I^2Rt$, where W is the weight or volume of the electrode melted by I current in "t" time. If "t" represents the unit of time, then it is evident that the melting rate is proportional to the square of the current and to R, the specific resistance of the core-wire of the electrode.

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Taking into consideration that all commercial mild steel electrodes are supposedly hot drawn wires and should be in a fully recrystallized condition, then the specific resistance of such wires is a function of their C–Mn content, provided that the non-metallic constituents are present in normal proportions and are uniformly distributed.

As the C–Mn proportion is maintained practically uniformly in these steels, it might be ultimately declared that the specific resistance of the electrode material is a function of its carbon content only.

Realizing that the specific resistance of a 3/16-inch diameter electrode core of 0.06 per cent C. content is .00185 ohms per linear foot, and that of a 3/16-inch diameter electrode core of 0.16 per cent C. content is .00236 ohms per linear foot, it is apparent that at approximately the same current density, the melting rate of the above given lower C. electrode is approximately 22 per cent slower than that of the higher C. electrode mentioned. This explains the long formation periods that exist during deposition of electrodes with cores at the lower end of the carbon range. The lower the carbon contained, the greater is the viscosity of the molten metal at the tip of the electrode. The greater viscosity permits the accumulation of a greater mass before it is separated from the electrode. When this separation is due to the presence of magnetic forces plus gravity, then the situation is not as bad as it is when the separation is done by magnetic forces only, as in position work. But even in horizontal downhand work, when the separation of the drops is aided by gravity, the arc transfer of the bulky globules is hesitating. During this hesitating or whirling period the exposure to atmospheric contamination is abetted to the detriment of the physical properties of the weld metal. The higher carbon content electrodes, as pointed out above, melt at a faster rate and the viscosity of the molten globule formed is proportionately less as the C. content increases. The more liquid globule offers less resistance to the forces that tend to separate it from the tip of the electrode and becomes detached as soon as formed. Being relatively small, the existing forces, magnetic and earthly being in better proportion to its lesser weight, are capable of hurling it directly onto the crater at a maximum speed through the arc. Thus the

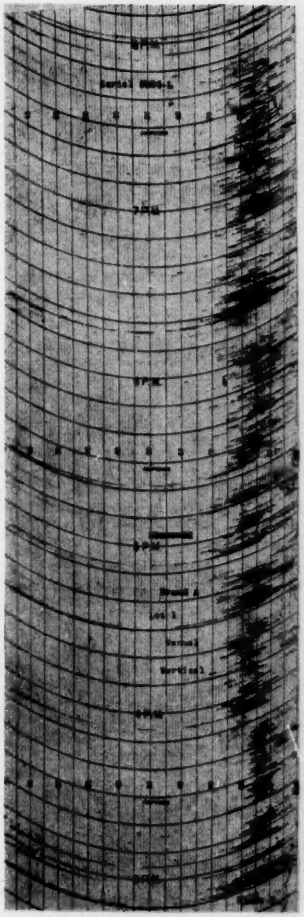

FIGURE 1.

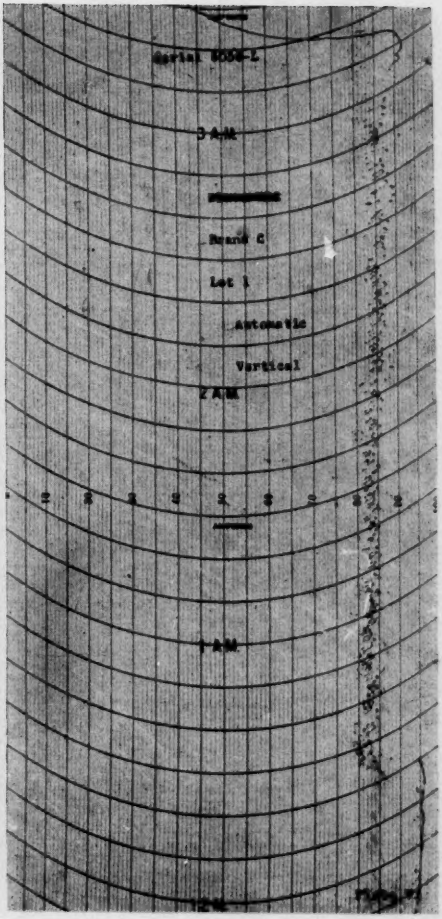

FIGURE 2.

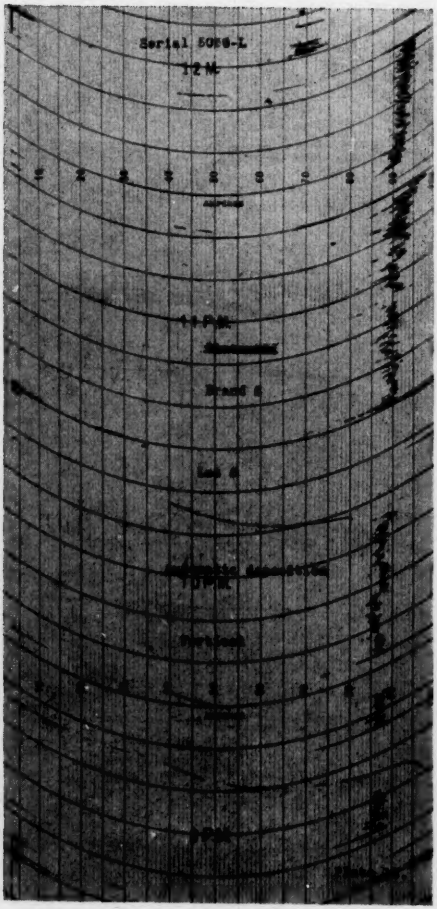

FIGURE 3.

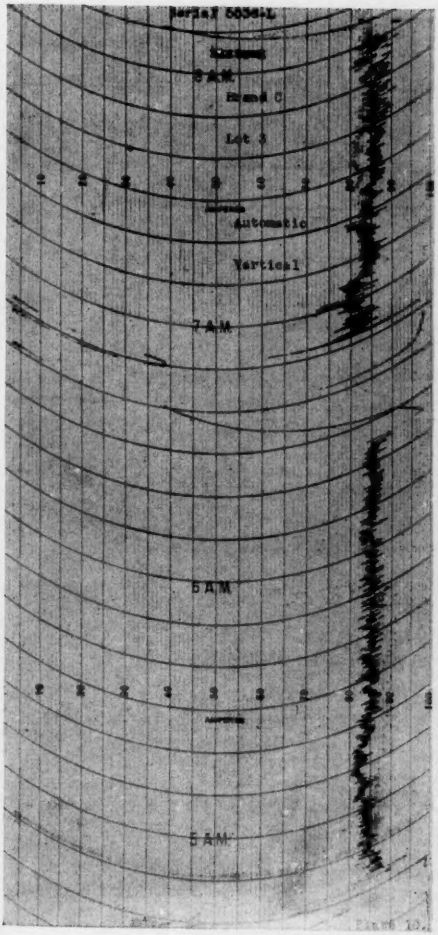

FIGURE 4.

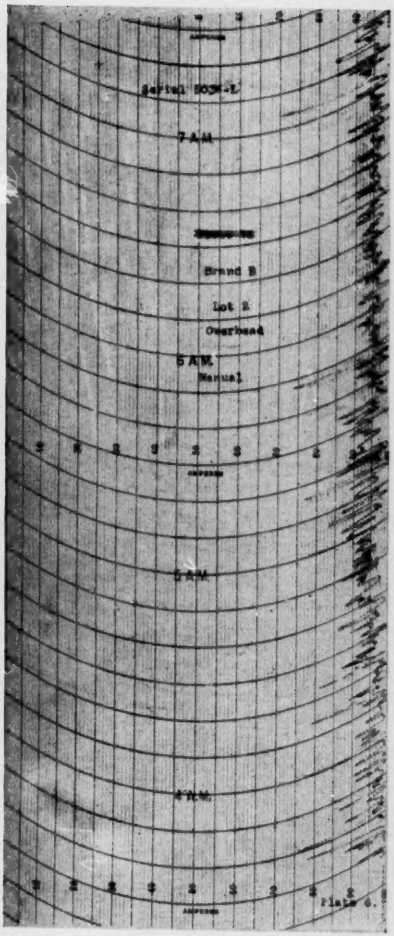

FIGURE 5.

time of exposure to atmospheric contamination is lessened and the surrounding vapor or gas shield may more efficiently protect the metal in transit through the arc than in case of the lower carbon electrodes.

To sum up—The formation periods of electrodes—with carbon content at the lower end of the usual range—are long, and so are their transfer periods. The formation periods of electrodes—with carbon content at the upper end of the usual range—are short and the transfer periods are much shorter than those of the lower carbon electrodes. The melting of the base metal occurs during formation periods. A relatively long part of the total time of deposition of low carbon electrodes is spent in transfer periods and the preparation of the base metal suffers in consequence as the arc intensity during long transfer periods is but a fraction of that existing during the formation periods. On the other hand, as the arc intensity hardly lessens during the swift transfer periods of the higher carbon electrodes, the greater part of their total time of deposition is available for melting base metal.

(2) The above summation practically implies the answer to the second question. As the arcronograph is, as pointed out by Lieutenant Commander Manning, primarily a time integrating recorder, it is bound to register a higher average for the higher carbon electrodes. Figures 1, 2, 3, 4 and 5, respectively, show typical arcronograph records obtained during the deposition of covered electrodes with cores of carbon content as given forthwith.

Figure 1.—0.03 per cent C., electrodes deposited in the vertical plane manually. Observe the wide amplitude of the chart, indicating the long whirling periods or sluggishness of the molten globules in transition through the arc.

Figure 2.—0.08 per cent C., electrodes deposited in the vertical plane with an automatic welding device developed at the EES. Compare the narrow amplitude of this record with that of the previous one. On account of the sluggishness of the 0.03 per cent electrode, it could not be deposited with the automatic device.

Figure 3.—0.10 per cent C., electrodes deposited with the automatic welder vertically.

Figure 4.—0.13 per cent C., electrodes deposited with the automatic welder vertically.

Figure 5.—0.26 per cent C., electrodes deposited overhead, manually. This electrode was too fast for automatic welding in position work.

Figure 6.—Shows a graphic illustration of the results of the physical tests plotted against the per cent C. contained in the electrode cores.

3. Concerning the agreement between arcronograph records and weld efficiency, a copy of two tests made at the Engineering Experiment Station is given below to illustrate the consistency of the method.

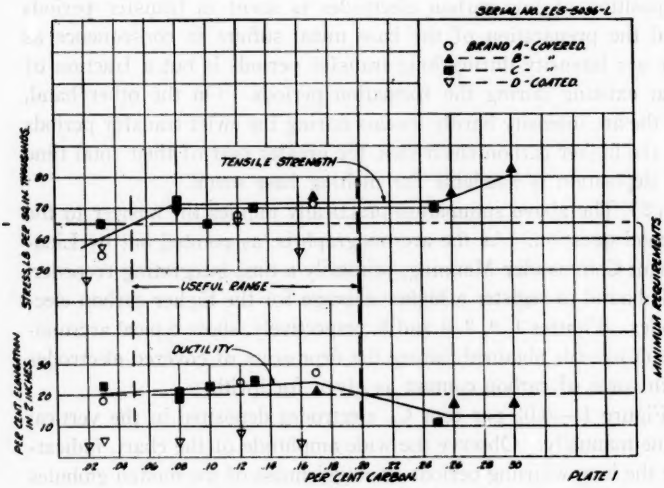

FIGURE 6.

Two 24 inches long seams were welded using ¾-inch plates. One seam was welded with coated electrodes, the other with high grade covered electrodes. All beads or layers were recorded by the arcronograph except as marked on the chart.

On completion of welding the arcronograph records were analyzed and a prediction chart was prepared as shown by Figure 7. The welded plates were then turned over the the Station's Metals Laboratory for tests. Figure 7 shows the method used in prepar-

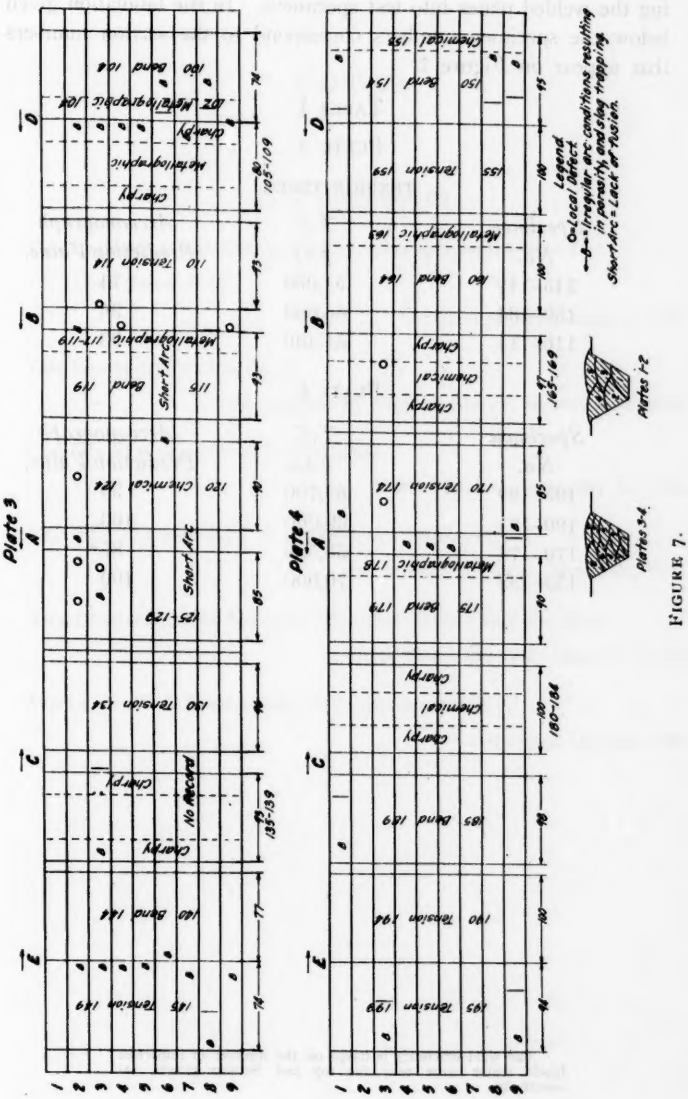
Plate 3
A
B
C
D
E
Plate 4
Legend
O—Local defect
—o— Irregular arc conditions resulting in poorly cooling trapping
Short Arc - Lack of fusion.
Plates 1-2
Plates 3-4

FIGURE 7.

ing the welded plates into test specimens. In the tabulation given below the specimen numbers correspond to the section numbers that appear on Figure 7.

TABLE I.

PLATE 3.

TENSION TESTS.

Specimen No.	*T.S. p.s.i.*	*Arcronograph Prediction Value.*
145–149	51,000	74
130–134	66,000	96
110–114	61,400	93

PLATE 4.

Specimen No.	*T.S. p.s.i.*	*Arcronograph Prediction Value.*
195–199	63,700	94
190–194.	69,000	100
170–174	69,550	85*
155–159	70,000	100

* The weld efficiency is based on the number of imperfect beads which were near the top and bottom passes, respectively.

NOTES.

INDEX TO NOTES.

The Launch of the Cunard-White Star Quadruple-Screw Liner *Queen Mary*.

Engineering, October 5, 1934.

The Launching of Big Ships.

Shipbuilding and Shipping Record, September 20, 1934.

Can We Eliminate the Fire Hazard?

Marine Journal, September 15, 1934.

Training and Research in Aeronautical Engineering.

The Military Engineer, Nov.-Dec., 1934.

The Development of Military Weapons Since the Civil War.

The Military Engineer, Sept.-Oct., 1934.

Welds for High-Pressure High-Temperature Piping.

Combustion, October, 1934.

THE LAUNCH OF THE CUNARD-WHITE STAR QUADRUPLE-SCREW LINER *QUEEN MARY*.

The coincidence of the launch of the Cunard-White Star quadruple-screw liner *Queen Mary* with our date for going to press, precluded us from doing more than making a very brief reference to the successful conclusion of the operation in the account of the vessel given in our last week's issue. We now, therefore, publish some details and illustrations of the launch itself in order to place on record this important step towards putting the vessel into commission. Although great advance has been made in the technique of launching since the *Great Eastern* stuck fast on her way to the river, the transference of a great mass of material from land to water is bound to be a matter of considerable concern to those responsible. Apart from the fact that the stresses in the hull of a vessel when she is supported only on her launching cradles are changed to others at the moment she becomes wholly waterborne, there is the fact that, once started, there is no means of correcting any error or combating any mishap. To the majority of the spectators the launch of the *Queen Mary* was a majestic spectacle only, but it was really an engineering triumph, the wholly successful conclusion of which came as a relief, however complete the confidence in the skill of the shipbuilders.

The launching weight of the *Queen Mary* was officially stated to be 40,000 tons, and the enormous bulk represented by it was, without the slightest hitch, transferred from the ways to the River Clyde in a fraction under 75 seconds. The work of clearing away the shores and blocks was, we understand, commenced early on Tuesday morning, September 25, and continued without intermission until a little while before the actual ceremony, which took place at 3:15 P. M. on Wednesday, September 26. During the operation, the ship "drew," that is, moved down the ways, a distance of some 2 inches, an amount which, taking her weight into account, cannot be considered material, and must have removed any fear of delay in starting when the triggers were released. The cradle and launching ways were on a scale commensurate with the ship. We are informed that the former was 850 feet long, and that the width of each of the two ways was 10 feet 6 inches. The timber of the forward part of the cradle was reinforced by a steel structure. The after part was continued up to the stern-tube bosses for the two inner propellers.

It will be noticed in the illustration just referred to that the drag chains were attached to the ship for about the first third of her length. There were 18 chains on each side. Some surprise was expressed at the number and weight of these chains, 2350 tons in all, but it must be remembered that the River Clyde is comparatively narrow at the launching point, in spite of the fact that the mouth of the River Cart is almost opposite. Circumstances therefore dictated this precaution; in cases where there is plenty of width of water the drags may be reduced in number, or even, as in the case of H.M.S. *Rodney*, launched at Birkenhead, omitted altogether. In the case of the *Queen Mary*, the drags were most effective, the vessel being pulled up very gently and coming to a standstill very promptly. One feature of the launch was the small amount of commotion and noise attendant on the operation of the drags, and the absence of any violent check. There were six triggers, arranged in three pairs, one pair forward, one amidships, and the remaining pair about 150 feet from the stern. They were electrically operated simultaneously by a push-button control from the launching platform. Six hydraulic starting rams were provided for emergency use, but, as far as we are aware, they were not required.

As regards the actual launching ceremony itself, even a steady and heavy downpour of rain did not detract from the impressiveness of its dignified simplicity. Their Majesties King George and Queen Mary and His Royal Highness the Prince of Wales reached the scene of the launch by way of a balcony arranged behind the stands on the starboard side of the vessel, from which a view was obtained of her full length. After acknowledging the welcome of the immense mass of spectators assembled on the starboard side, the Royal party, accompanied by Lord Aberconway, Sir Percy Bates, Sir Iain Colquhoun and Sir Thomas Bell, proceeded along an open gallery to the enclosed launching platform at the bows of the vessel. Here, after presentation of the civic dignitaries and the directors of Messrs. Cunard-White Star, Limited, and John Brown and Company, Sir Percy Bates read an address of welcome.

His Majesty the King, in his reply, said:

"I thank you for your loyal address of welcome to us. As a sailor, I have deep pleasure in coming here today to watch the launching by the Queen of this great and beautiful ship. The sea, with her tempests, will not readily be bridled. She is stronger than man; yet in recent times man has done much to make the struggle with her more equal. It is still less than a hundred years since Samuel Cunard founded his service of small wooden paddle steamers for the carrying of mails across the Atlantic to America. These first Cunard ships were of 1150 tons. A few people now alive must in childhood have heard those ships spoken of with wonder as evidence of man's mastery over nature.

"Today we come to the happy task of sending on her way the stateliest ship now in being. I thank all those here and elsewhere whose efforts, however inconspicuous or humble, have helped to build her. For three years her uncompleted hull has lain in silence on the stocks. We know full well what misery a silent dockyard may spread among a seaport, and with what courage that misery is endured. During those years when work upon her was suspended we grieved for what that suspension meant to thousands of our people. We rejoice that, with the help of the Government, it has been possible to lift that cloud and to complete this ship. Now, with the hope of better trade on both sides of the Atlantic, let us look forward to her playing a great part in the revival of international commerce. It has been the Nation's will that she should be completed, and today we can send her forth, no longer a number on the books, but a ship with a name in the world, alive with beauty, energy, and strength.

"Samuel Cunard built his ships to carry the mails between the two English-speaking countries. This one is built to carry the people of the two lands in great numbers to and fro, so that they may learn to understand each other. Both are faced with similar problems, and prosper and suffer together. May she, in her career, bear many thousands of each race to visit the other as students, and to return as friends. We send her to her element with the goodwill of all the nations as a mark of our hope in the future. She has been built in fellowship among ourselves; may her life among great waters spread friendship among the nations."

Lord Aberconway then presented a casket of hand-wrought and chiseled Staybright steel, mounted in gold and silver guilt, to her Majesty the Queen, who was then requested by Sir Thomas Bell to name and launch the ship. Her Majesty thereupon cut a ribbon releasing a bottle of Australian wine, which broke against the bows, and said, "I am very happy to name this ship the *Queen Mary*, and I wish success and good luck to all who sail in her." Immediately afterwards Her Majesty pressed the button controlling the trigger release, and with but a few seconds delay, the vessel commenced to

move. About 54 seconds were occupied in her journey down the ways, after which a further 21 seconds sufficed to bring her up into a position ready for the waiting tugs to take hold.

At the conclusion of the ceremony the Royal party returned to the open balcony, where another presentation was made to them, this time of six of the oldest employes of John Brown and Company, all of whom had been in the firm's service for over fifty years. These were, James Dunsmuir, head foreman engineer; John Reavey, brass finisher; John Conolly, boiler works machineman; David McCutcheon, assistant shipwright foreman; James Thomson, plater, and James Martin, riveter. The singing of the National Anthem concluded the ceremony, and the Royal party then left the shipyard.

During the tea provided for a portion of the guests in the mold loft, Sir Percy Bates subsequently stated that it was the first occasion on which the King and Queen had been present at the launch of a merchant vessel, and referred to the harmonious relations which had existed between the Cunard-White Star Company and the shipbuilders. He paid a tribute to Sir Thomas Bell, than whom, he said, he would want no better partner in either good or difficult times, and warmly commended the sterling work done by other officials of Messrs. John Brown, mentioning particularly Mr. Pigott, Mr. Skiffington, and Mr. McNeill, while the part played by the technical staff and the workmen was not forgotten. He concluded by a reference to the assistance given by the Government to the enterprise, and stated that its arrangements with them included the provision of a second ship. "As soon as we are less pressed," he said, "with the work on the ship which has just been launched, we shall turn our attention in that direction, for a second ship will be necessary to reap the full measure of success for which we have planned."

It may be mentioned that the *Queen Mary* is expected to be ready for commission in April, 1936.

Immediately the ship was launched the tugs took charge and conveyed her to the fitting-out basin parallel to, and not far distant, from the building berth. The vessel was handled with remarkable facility, and except for the fact that part of the forecradle came into slight contact with the corner of the jetty, the task was carried out without difficuly, berthing being concluded about 4 o'clock, and the men employed on it being able to leave the yard at the usual hour of 5 o'clock.—"Engineering," October 5, 1934.

THE LAUNCHING OF BIG SHIPS.

Factors Which Have Been Considered for the Launch of the Cunard-White Star Liner.

Unusual interest at the present time attaches to the subject of launching big ships, in view of the approaching launch of the Cunarder. While the initiated know the intricacies associated with launching, to the general public the operation is simply a thrilling spectacle.

Fundamentally the operation is well known. During the building of a ship the structure is supported by blocks and shores, which are removed at the proper time, the weight being transferred to a cradle which slides on prepared ways towards the water. To effect this, two sets of ways are built, namely, the standing ways, placed suitably apart, which run underneath the vessel from the stem, right aft, and into the water a sufficient length to insure a depth of water at the aft end of the standing ways as the calculations demand; and the sliding ways which are then introduced. These extend as far as practicable under the hull itself, being usually 85 per cent of

the vessel's length. They are prepared in sections, and in very large vessels these sections are slid in from the fore end of the standing ways to their proper stations. Large wedges are then forced home between the top of the sliding ways and the hull of the ship, so that when the bilge blocks and shores supporting the hull are withdrawn the weight is borne by the sliding ways. Before the sliding ways have been placed in position the rubbing surfaces of the standing ways and sliding ways have been carefully greased. When the bilge blocks and shores have been withdrawn a strong force is then in action, tending to cause the vessel to slide down the ways, for these have been given a declivity of about ½ inch per foot. With the release of the dog shores or triggers the ship is free to move.

The sliding ways carry the vessel into the water. At first the movement may be very slow, and if this is imperceptible pressure is exerted by powerful rams on the forward end of the sliding ways.

On the passage down the ways the speed gradually increases, then with the entrance of the stern into the water a retarding action comes into play. In addition, especially in restricted waters such as the upper reaches of the Clyde, drag chains come into operation when the vessel is water-borne.

The maximum speed of the vessel down the ways may be as much as 20 feet per second, or about 12 miles per hour.

The actual timing of the *Hood* showed that the operation from beginning of her movement down the ways until she was at rest in the river lasted only 100 seconds.

The investigations carried out for large vessels include:—

(1) A close estimate of the launching weight and position of the center of gravity.

(2) An estimate of the stability of the ship during and after launching.

(3) Calculations to determine the run before the stern lifts, the pressure on the fore poppets at lift, the minimum moment against tipping, the distribution of pressures, etc.

(4) An estimate of the structural strength of the ship girder during launching.

(5) Experiments to determine the suitability of the tallow and lubricants proposed for the sliding surfaces.

Such investigations were carried out in connection with the launches of the *Nelson* and *Rodney*, and the results of these are contained in Sir W. J. Berry's paper in the 1926 volume of the Transactions of the Institution of Naval Architects. It is interesting in this connection to note that the calculations were based, in the case of the *Nelson*, on an expected high tide over the way ends of 13 feet 4 inches, whereas in the case of the large vessels launched on the Clyde a height of water over the end of ways of from 8 to 9 feet is as much as can generally be obtained. Experience has shown this to be satisfactory.

The general particulars gleaned from the launches of large ships serve for future guidance, and the following figures for the *Hood* show the nature of the information collected. These particulars were published with the authority of the Admiralty in the Transactions of the Institution of Naval Architects, vol. lxviii.

Launched	August 22, 1918.
Length between perpendiculars	810 ft.
Declivity of chord of ways	9/16 in. per ft.
Camber of ways	16 in. in 813 ft.
Length of ground (or standing) ways	813 ft.
Length of sliding ways	677 ft. 6 in.

Breadth of ways	6 ft. 9 in.
Area of sliding surfaces	9146 sq. ft.
Ways apart, outside to outside	31 ft. 9 in.
Fore edge of poppet from fore pendicular	79 ft. 3 in.
Launching weight	22,440 tons.
Center of gravity abaft amidships	33.4 ft.
Water on end of ways	8 ft.
Poppets from way-end when stern lifts	239 ft.
Weight on poppet when stern lifts	5250 tons.
Mean initial pressure on grease	2.45 tons per sq. ft.
Pressure on grease when stern lifts	13 tons.
Maximum load per foot run on way-end during passage of midship body	99.2 tons.
Corresponding pressure on grease	7.35 tons per sq. ft.
Least moment against tipping	1,030,000 ft. tons.

Drags, nine in number each side, of total weight 1260 tons, were employed to arrest the ship.

The launching weight of No. 534 will be very much greater than that of the *Hood*. The areas of the sliding surfaces have been determined from consideration of this launching weight and the mean initial pressure on the grease, which in the case of the *Hood* was almost 2½ tons per square foot. The important factors which demand the particular attention of those responsible for the launch are the fore poppet pressures and moment against tipping. These are determined by direct calculation, and the fore-poppet structure made sufficiently strong to meet the enormous strains to which it is subjected.

Hidden from view at the time of the launch is the internal shoring of the ship. During the passage of the vessel down the ways she is subjected to stresses which are not met with when on the building berth or when afloat. In order to meet these a tremendous amount of internal support has to be fitted.

While the preparations for a big launch give cause for a great deal of careful study and thought, and not a little anxiety is felt until the accomplishment of the operation, the experience gained in large shipyards affords confidence that, notwithstanding the size of No. 534, her transit will be successful.—"Shipbuilding and Shipping Record," September 20, 1934.

CAN WE ELIMINATE THE FIRE HAZARD?

Some Technical Considerations Growing Out of the Latest Sea Disaster.

The tragic destruction of the *Morro Castle* by fire when within thirty miles of port with the loss of more than a hundred passengers and members of her crew, has brought home to all of us the fact that life is still unsafe at sea despite the vast improvements that have been brought about as a result of previous disasters. Here was a vessel generally regarded as the "last word" in modern ship construction. The company owning and operating the *Morro Castle* set out at the very beginning to design and construct a luxury liner that would concentrate all of its previous experience into a vessel that could withstand not only the heavy weather frequently encountered in the Caribbean, but would offer the maximum degree of safety possible on shipboard. Representatives of the Ward Line mulled over the

plans of this vessel for almost two years before the actual design was finally undertaken by one of the world's greatest naval architects. The work of actual construction was carried out in the great yard on Hampton Roads where countless vessels that have made sea history were built.

This ship contained every known device to safeguard the lives of passengers; she had the latest fire detection system and fireproof bulkheads and her machinery worked with such precision that she never failed during the four years of her operation between New York and Cuban waters to arrive within five minutes of her scheduled time. Her commander, Captain Willmott, who was largely responsible for many of the modern improvements and innovations worked into her construction for the convenience and safety of passengers, was a man of integrity, experience and great personal courage. His unexpected removal from the scene of command just prior to the crisis, marks one of those inscrutable ironies of Fate which form the substance of which epochal drama is made. Notwithstanding all of these precautions and the unstinted expenditure of money and skill, the *Morro Castle* came to grief under harrowing conditions that have left a profound impression of helplessness upon the minds of all whose daily lives bring them into contact with the sea and its varied uncertainties.

If the *Morro Castle* could meet this sad fate, fitted as she was with every modern scheme of prevention, there is not a ship afloat that could not, under the same conditions, meet a similar end; allowing, of course, for the human element which is always an imponderable.

There was a time some years ago when the principal concern of marine engineers centered about preventing sea disasters through failure of bulkheads. Immediately following the *Titanic* disaster in April, 1912, a great impetus was given to international conferences designed to prevent the recurrence of a similar disaster. As a result of these conferences, collision bulkheads were raised higher than before and ships were divided into more watertight compartments than had been the usual practice. Stringent lifeboat rules were laid down and generally enforced and the code called for lifeboat drills at frequent intervals. Since this new defense against collision, there have been practically no spectacular losses that might test the efficacy of the new construction code, though the lifeboat code has, upon several occasions, proven far from satisfactory; as in the comparatively recent case of the *Vestris* which foundered off the Virginia Capes with the loss of 111 lives, most of them passengers.

Within the past few years, however, there have been several serious losses due to fire. The *Bermuda*, a modern ship in every respect, burned twice and was finally abandoned as a total loss; the *Georges Philippar* was destroyed by fire with serious loss of life, while another modern French liner, the *L'Antique*, met a similar fate shortly thereafter. These were all modern ships fitted with the very latest protective devices and, before the event, believed to be proof against both the ravages of fire and the hazards of collision. But all of them burned just the same and the fires were discovered to have originated in the superstructure as in the case of the *Morro Castle*.

It is believed that efforts to safeguard a ship from collison hazard have been successful. We now have three and four compartment vessels fitted with extremely high and strong transverse bulkheads that are expected to save the ship and her passengers and crew in case of collision. The efficiency of these improvements has not as yet been proved by the test of a major event within recent years, but there is a strong belief among marine engineers that modern ships properly fitted with compartments and bulkheads will remain afloat when the catastrophic test comes.

But it is evident that we have not mastered an equally great hazard which appears in its most dangerous form in the superstructure fire. Hold fires seldom endanger human life. Many ships have such fires and they are often put out without much trouble or loss. In cases where hold fires are severe, the ship usually makes port where additional fire-fighting facilities are available to cope with it and save the ship.

There is but one answer to the problem of preventing superstructure fires and that is complete fireproofing of all materials entering into the construction of living quarters and public spaces. On the new French liner *Normandie* it is proposed to segregate any fire that may break out by constructing the retaining walls of all enclosed spaces of metal base, lined with asbestos. It is proposed in this case to continue the use of woodwork and furniture as at present on the theory that any fire can be confined to seat of origin. Following the *Morro Castle* fire, however, it is possible that legislation will be introduced in the next Congress making mandatory the use of fireproof materials throughout the entire ship with especial reference to the superstructure. This will, necessarily, involve increased cost for materials, though it is not likely that any of the decorative advantages will have to be sacrificed. It would not be surprising if America takes the lead in this direction.

This will mean that all superstructure living spaces, together with all parts of any ship to be built in future, will be constructed of fireproof materials, including bulkheads, ceilings, decks, stairways, furniture, beddings and tapestries. This has already been done in the case of the wardrooms and staterooms on modern naval vessels, the interior of modern Pullman cars and of the ultra-modern streamlined passenger trains. Existing ship superstructures may be improved as regards fireproofing in many respects, but it is not likely that they can be entirely rebuilt because of the excessive cost. Much can be done, however, and a start made by fitting the public spaces and passenger cabins and staterooms with metal furniture, fireproof hangings and mattresses and bedding made and stuffed with non-inflammable materials.

At the time the *Morro Castle* and other modern passenger vessels were built it was not considered feasible or practicable to construct the living spaces and superstructure of fireproof materials. There were several reasons for this, including cost, materials available and artistic considerations. For many years the idea persisted in marine circles that in the event of a vessel sinking or of the crew and passengers abandoning ship, it was desirable to have all pillows, mattresses, cushions and similar stateroom utilities constructed with materials of sufficient buoyancy to support an adult in the water. Because of this it has been common practice to stuff such articles of bedding with kapok, an extremely inflammable material which once afire is almost impossible to extinguish.

Aside from the human equation, which in any disaster on sea or land is always unpredictable, it seems reasonable to assume that the naval architects have segregated the various hazards by what might be called a process of elimination. The great danger now to be overcome is that of fire. This can be done by substituting fireproof materials wherever possible in the construction of public spaces and living quarters aboard ship. If the unfortunate *Morro Castle* should prove to be the means of bringing about this great and needed reform, her tragic loss will not have been in vain.—"Marine Journal," September 15, 1934.

TRAINING AND RESEARCH IN AERONAUTICAL ENGINEERING.

ALEXANDER KLEMIN, S.M., LL.D.*

Aeronautics is a comparatively modern branch of engineering, but it has come to the fore in a scientifically-minded age, and hence its technical bases have been the object of intensive research, and its practitioners are being carefully trained along specialized lines. Though the Wright Brothers made their first flight only in 1903, we find perhaps fifty or sixty aeronautical schools and laboratories busily at work in every civilized country, and the literary output in this field of applied science is enormous. Since aeronautics is a vital element in national defense, it is not inappropriate to discuss the allied activities of training and research in the columns of "The Military Engineer."

There are engineers of all branches engaged in aviation, mechanical, civil, electrical, internal combustion engine men and so forth, but the name of aeronautical engineer should properly be confined to those men who apply the science of aerodynamics or air flow in the design, construction, and operation of airplanes, airships, and other types of aircraft.

In the early days of pioneer effort the design and construction of aircraft was the work, frequently, of bold, adventurous, and mechanically-gifted men who, with little technical knowledge, built by a process of trial and error, reaping fame and fortune if they succeeded, encountering fatal or serious accidents if they failed. Watching an air meet or exhibition, particularly when a new type of airplane was involved, gave the public a thrill not unlike that provided by a lion tamer.

Nowadays a successful aircraft designer has a much more solid technical foundation to build upon. Too early specialization in the art is unwise. It produces narrow and partially ignorant men. The writer has frequent occasion to point out to engineering freshmen or sophomores that they had better learn fundamentals first, and leave airplane design to a later date. This view is supported by the practice of all the reputable schools of aeronautical engineering both in the United States and abroad.

The first three years of training for an aeronautical engineer should be devoted mainly to mathematics, physics, mechanics, engineering drawing, and mechanical engineering in general. It is only in the senior, or even in a graduate year that specialization becomes advisable. In fact a number of American schools reserve all aeronautical engineering specialization to graduate work.

But in all American aeronautical schools, whether part of a university or a technical school, and whether the work is done in the senior or a graduate year, the most fundamental and most important subject of study is, of course, aerodynamics.

The air is all pervading, but invisible, and hence its laws of flow are still only partially understood even after centuries of study. The approach to aerodynamics is highly mathematical, but can not be entirely mathematical. In hydrodynamics, the mathematician has built up a wonderful realm of pressure, velocity, stream function, and potential, in which no problem of flow is insoluble; but, unfortunately, in classical hydrodynamics, viscosity is neglected, mainly because the equations of motion are insoluble when viscosity is introduced. And the classical non-viscous flow only gives hints of the actual viscous flow. It is true that, in recent years, there has been some bridging of the gap, and, with the aid of Prandtl's conception of the boundary

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layer, much closer approximations to the actual viscous flow are possible. For the engineer, such theoretical studies, at least in their elementary stages, are indispensable, but an experimental approach is also necessary.

For this experimental approach, the essential weapon is the wind tunnel. It may be postulated that the air forces on a body are the same, at the same relative speed, whether the body is moving through the air or the air is moving past the body. Since it is much easier to record forces and moments on a stationary object, the model in a wind tunnel is held at rest while the air is drawn past it by a powerful propeller-type fan. The wind tunnel is apt to be in the form of a Venturi tube, with the working section at the throat or waist of the Venturi where the airspeed is naturally the greatest; working sections in the university laboratories range from a diameter of 4 to 10 feet, and the average wind speed on test is around 60 miles per hour.

In this working section, models of various aerodynamic bodies may be suspended, airfoils, airplanes, spheres, airships, et cetera, constructed to very accurate scale, with tolerances of 1/200 inch. Fine well-seasoned mahogany is considered the best material.

Above the working section there is generally placed a six-component balance, or weighing apparatus, from which the model under test is suspended by fine piano wire. A whole technique, simple in principle but growing more complicated in execution, has grown up for the determination of lift, drag or air resistance, pitching moments, and other aerodynamic data.

No school of aeronautical engineering can possibly be considered entirely effective if there is no provision for wind tunnel work by the senior or graduate student. Students enjoy wind tunnel work immensely, and profit greatly therefrom. As the field of applied aerodynamics is far from having reached the point of diminishing return, graduate students in particular can, when suitably guided, make their wind tunnel thesis a worth while contribution to knowledge. A similar contribution to engineering knowledge is probably a matter of much greater difficulty in other branches of engineering.

The present article is not intended to replace the catalogues of the excellent schools working in this field. Still it may be of interest to enumerate briefly the most subjects of specialized work.

The calculation of the performance and stability of aircraft is a fascinating and essential part of the aeronautical engineer's training. There are no more beautiful applications of the dynamics of bodies to be found than in the stability and complicated maneuvers of the airplane or airship. Aircraft-propeller design is on a more solid theoretical basis than marine-propeller design and is an instructive phase of the student's work. The airplane propeller is considered as being composed of airfoil elements, and the motion of individual blade elements and the integration of forces on such elements is a complicated and interesting study. The structural calculation of an aircraft, or stress analysis, as it is generally termed, is perhaps more refined than that of any other engineering structure. The structural analysis of a bridge may be a difficult matter, but the bridge analyst is not so rigidly restricted in the matter of weight, and a bridge need not be analyzed for a condition where it performs a loop or somersault in the air! The essential lightness of aircraft, which must not be coupled with fragility, makes the study of metallurgy, light alloys, and advanced methods of construction imperative. Instruments, aircraft engines, and other similar courses provide a very busy year or two for the best men.

At least in the school which the writer has the privilege to direct, the high point of the whole curriculum is in the complete design of an aircraft to given specifications. The student, for example, may be asked to design, carrying the work through for an entire year, a fast transport airplane to

a given specification and in accordance with Department of Commerce specifications. In such a design it is necessary to consider speed, climb, landing-speed range, stability, maneuverability, pay load, pilot and passenger accommodation, a complicated power plant installation, lightness and strength of structure, flying and navigation instruments, installation, et cetera. Detail design of fittings and connections, construction costs, maintenance, and inspection are equally important. Then come innumerable subsidiary problems such as heating and ventilation, noise-proofing, toilets and ash trays, windows and indirect lighting. The design of a very large airplane is best comparable in complexity and comprehensiveness to the design of an ocean liner.

The airplane design carried out by the student himself is the best touchstone of his ability as an aeronautical engineer. An understanding of aeronautics and an ability in mathematical analysis do not constitute an aeronautical engineer. There must be superimposed the ability to visualize objects in three dimensions, and to embody the visualization in mechanical drawing, the language of the engineer. Instinctive mechanical ability—not to be acquired in any university or technical school in the world—is as important as in any branch of engineering.

To some young men professional work of this sort is almost an agony and a warning to enter some other field of human activity. To others it is stimulating, challenging, and fascinating. Students—a most extraordinary thing, to those who live in universities—will work late night after night on their particular design, and competent airplane constructors, judges in the annual design competition are sometimes amazed by the quality and quantity of the work.

The Aircraft Yearbook of 1934 gives an extraordinarily long list of universities and technical schools, scattered throughout the states and offering complete courses and degrees in aeronautical engineering. Space considerations will not permit us to list these schools with their facilities. Without saying that they are pre-eminent, we may safely say that at least real prestige attaches to the schools endowed in whole or in part by the late Daniel Guggenheim, generally through the instrumentality of the Daniel Guggenheim Fund for the Promotion of Aeronautics—at the California Institute of Technology, Georgia School of Technology, Massachusetts Institute of Technology, New York University, Stanford University, University of Michigan, and the University of Washington.

In interviewing young men or their parents, the writer is inevitably drawn into a discussion of the outlook for the profession, and avoids with difficulty the rôle of a prophet. It may be said with considerable assurance that aviation is only in its early stages, that it will inevitably grow in technical achievement and will assume the proportion of a gigantic industry. So much remains to be done, that the opportunities for skill, study, ingenuity and inventiveness are unlimited. Aviation is a young man's industry, and the most noted aeronautical engineers who have achieved both fame and fortune are all men in their early forties. On the other hand, the universities interested in aeronautics undoubtedly supply far too many graduates; the keenest young minds are attracted to the profession, and the competition is intense. Perhaps the situation may be best summarized by saying that the profession of aeronautics holds out both a greater hope of eminence and financial reward, and a greater possibility of elimination from its ranks than other fields of engineering.

Aeronautical research via the wind tunnel, the structural laboratory, the engine laboratory, experimental construction, and flight testing is conducted by the Army Air Corps mainly at its station at Dayton, Ohio; by the Navy

at the Washington Navy Yard and the Philadelphia Naval Aircraft Factory; and by some of the major industrial companies such as Curtiss-Wright, United, Aviation Corporation, et cetera. Laboratory work, par excellence, is carried on by the N. A. C. A. at Langley Field, by the Bureau of Standards, and by the universities. Langley Field is unrivalled anywhere in the world as to facilities and results. The Daniel Guggenheim Schools probably as a group have more mature and "broader" personnel, and make a more limited but more original and expeditious approach to research than the government laboratories. Each governmental unit is fully justified in its sphere of activity and, while greater coordination is conceivable, coordination also spells centralization and minimizes originality. Greater cooperation between the N. A. C. A. and the universities—analogous to practice in England, France, Germany, and Italy is probably highly desirable.

But, however organized and however it may be improved, we may safely say that the sum total of aeronautical research in the United States, whether theoretical or applied, is now unequalled by any country in the world. This statement is made after considerable reflection and without any bias whatsoever. It is not the result of greater intelligence, but of a combination of resources, geographical conditions and other fortunate circumstances which prevail and will prevail in spite of the innumerable difficulties American aviation has had to meet.

Granted these superb facilities, these well trained men, and these many agencies, the question arises: Is there still a field for aeronautical research?

The answer is definitely in the affirmative, as British Parliamentary practice has it. One of the reasons for seeking longevity by a man whose heart is in aeronautics, is the unlimited scope before him. Each new advance seems to be but an invitation to further conquests.

The direct lift or helicopter type of aircraft remains to be successfully produced. Stratosphere flying is just ahead of us with unlimited speed in the offing. This requires a study of high speed phenomena, the evolution of airfoils suitable for bullet-like speed, jet or rocket propulsion, compressibility of air for passenger use, and many other questions. Complete noise proofing, weather prediction, fog flying or the dissipation of fog, seaworthiness of a flying boat in the North Atlantic, automatic stabilization and control, transmission of power to controls, steam turbines for altitude use, roof or dock landings via the autogiro or gyroplane, slow and safe landings for the airplane, increase of pay load. This is but a partial and unsystematic list of the many arduous and important things to be achieved.—"The Military Engineer," Nov.-Dec., 1934.

THE DEVELOPMENT OF MILITARY WEAPONS SINCE THE CIVIL WAR.

M. E. Barker, Captain, Chemical Warfare Service.

Our Army is frequently accused of being ultra-conservative and against any change in equipment, technique, or tactics. Usually such charges are made by persons who have no conception of the requirements of military weapons or the difficulty and cost of discarding an item of equipment and supplying a whole army with the new article of issue; teaching all concerned how to store, use, and care for the new weapon; and developing the proper technique and tactics of employment of the new weapon. It is a fact, however, that all armies are conservative and will not discard a proven weapon until the new item has shown its superiority in extensive field service or in battle. Simplicity of operation and reliability under field conditions are the basic requirements for any weapon. Changes in weapons are

thus comparatively slow because any satisfactory military weapon must be so nearly fool-proof that a tired, hungry, cold, scared soldier can operate the weapon satisfactorily.

It frequently happens that the production of weapons must wait until satisfactory materials of construction, or processes and tools of manufacture are found, and numerous related manufacturing problems are solved. For instance, a breechloading cannon was made in 1400, but the first practicable breechloading field gun was not produced until about 1860, although many different models were tried in the meantime. White phosphorus was discovered in 1668 by Brand, but it had no military usefulness until the development of the electric furnace two hundred and fifty years later made possible the manufacture on a quantity basis. The Army is, therefore, vitally interested in industrial processes as a means of producing the desired weapons. On frequent occasions, the Army has pioneered in manufacturing operations, as, for instance, in the complete interchangeability of parts which was first introduced by Captain John H. Hall, Ordnance Department, about 1832, in the manufacture of breechloading army muskets. The Army prefers to have its weapons made by industrial concerns, but when the process is especially difficult or especially dangerous, the manufacture in part and the assembly and testing may be carried out in government arsenals and shops.

In spite of the cost, manufacturing difficulties, and human inertia to new ideas, numerous changes in weapons have taken place in the memory of men now living. In this connection, the author has chosen the Civil War as the dividing line where material begins to approach man power as an important factor in war. As a matter of fact, this era may be dated from Pickett's charge at Gettysburg, in 1863, when a brave army, superbly led, was slaughtered by the fire power of almost modern weapons. Yet it is a curious fact that practically all writers on the Civil War devote so much of their attention to men and so little to material.

Let us, therefore, determine the status of the various weapons at the time of the Civil War and trace their development down to the present and make some guesses as to the probable future developments that may be expected.

RIFLES.

A great variety of rifles were used in the Civil War. They ranged from flintlock muzzle-loading smooth-bore muskets to Spencer repeating rifles, using fixed metallic cartridges. At the close of the Civil War the principal arm of the infantry was the muzzle-loading Springfield rifle of models 1855 and 1863, while the cavalry was armed with Spencer repeating carbines. Some few breechloading, heavy, single-shot rifles were in use by sharpshooters. The first breechloading rifle adopted for the infantry was made in 1865, as the Springfield model 1866, by converting the 1863 muzzle-loading rifle into a breech loader. With only slight modifications, this rifle was used as the standard arm until 1898, when the 30-caliber Krag-Jorgensen box magazine bolt-action rifle was adopted. The single-shot Springfield was used by some of our troops in the Spanish-American War. All rifles, during the Civil War, used black powder as the propelling charge. The Springfield tip-up breechloading rifles of models 1866-1873-1886 all used black powder only. Pyrocellulose smokeless powder was used in the Krag. In 1904, a modification of the Mauser action, using a clip loading device, was adopted as the model 1903 30-caliber Springfield rifle (bolt action) which continues to be the standard after 30 years. Especially selected heavy Springfield barrels, fitted on a suitable stock and sighted with receiver or telescopic sights, are today standards of accuracy all over the world for sportsmen and target shots.

In the meantime, the automatic type of rifle has been developed from the machine gun. The Browning machine rifle was the standard rifle of this type during the World War and remains so today. Since the World War this rifle has been much improved in firing possibilities by screwing a compensator on the muzzle, which prevents the rifle from climbing when fired at full automatic.

At the present time a semi-automatic shoulder rifle is under development. Rifles submitted by numerous inventors have been tested by the Ordnance Department and limited numbers of these rifles made for service test in the hands of troops. The Garand rifle is a very promising current development, but it will require further simplification in design and increase in reliability before it can be considered satisfactory for general issue to troops.

While these changes in the army rifle have been made, numerous improvements have been made in the small arms industry generally. Today one can buy a bewildering array of lever action repeaters, bolt action repeaters, and semi-automatics suitable for shooting any game from English sparrows to elephants. The most powerful, and one of the most accurate, guns in the world today, designed to be fired from the shoulder, is the 35.5-caliber Halgar Super Magnum, shooting a 240-grain bullet at muzzle velocity of 3125 feet per second. This weapon strikes a blow about twice as hard as the Springfield. In the hands of an expert marksman, this weapon is capable of disabling light armored cars and ordinary motor vehicles. The rifle, fitted with a good telescopic sight, sells for $910, and the cartridges retail at 50 cents each.

Recently a new type of rifle has been invented by Gerlich which may have a very important bearing on future military operations. This weapon fires a bullet, fitted with two flanges, through a barrel which has a large diameter near the breech, then a forcing cone and finally a small section of an appropriate diameter for the body of the bullet. During the movement of the bullet through the large section of the barrel, the two bands offer little friction but a good gas seal. High velocities are possible with this weapon with moderate gas pressures and progressive burning powder. During the passage through the forcing cone, the flanges are forced back into appropriate grooves in the body of the projectile. Muzzle velocities of a mile a second are claimed for this gun. Such a weapon, if actually made practicable for trained snipers in the field, will introduce a serious complication for light tanks and mechanized vehicles, as a bullet traveling at such velocities will penetrate armor suitable for such vehicles.

Bullets used during the Civil War were pure lead, or, at most, lead slightly hardened by some other low melting metal. Owing to the constantly increasing velocity of military arms, it has been necessary to form bullets with lead cores and a tough, ductile outer jacket for ordinary use; and bullets with a tool steel core and tough ductile jackets for armor piercing purposes. Copper, nickel, and cupro-nickel alloys are used for modern bullet jackets. The present tendency is toward lighter, high velocity bullets and lighter, shorter weapons for the military service, as shown by the following table of United States rifles.

Springfield Model	Length of Barrel Inches	Weight of Bullet Grains	Diameter of Bullet Inches	Muzzle Velocity Ft. Sec.
1863*	36	560	.50	1000
1873-86	32.5	400	.45	1300
1898	30	220	.30	2000-2200
1903	24	172	.30	2600-2700

* Last muzzle loader.

PISTOLS.

The Colt and Remington six-shot revolvers, cap and ball loading, were mostly used during the Civil War by the cavalry. The single-action model was preferred although the double-action revolver had been brought out in 1855 by Adams. About 1866, breechloading arms, using metallic cartridges, were adopted by practically all countries, and the Colt, Remington, and Smith and Wesson revolvers of 45 caliber became Army standard. Later the bore of army revolvers was reduced to .38 inches. The light bullets from these guns gave good penetration, but lacked the knock-down blow desired in a gun of this type. An automatic Colt pistol of 45 caliber was adopted as a result of the experiences of the Army with Moro outlaws in the Philippines. This pistol is known as the Colt 1911-model automatic pistol. It is one of the most reliable firearms made. Minor improvements in the grip and balance of this gun have recently been made, but no essential changes in the mechanism have been found necessary to date.

MACHINE GUNS.

Two types of machine guns were used during the Civil War. The "Organ Gun," which had been in existence for several years, was much improved and named "Requa Battery." It consisted of twenty-five barrels, mounted horizontally on the axle of a stout two-wheel cart. The breech of all the barrels was in one piece. The upper half of the breech was lifted and a strip of twenty-five paper cartridges, containing powder and bullets, was inserted. The several barrels were connected by a quick match which was fired by a single percussion cap in the center of the breech. The barrels fired in succession on both sides of the center as the quick match burned. It was said to be very effective.

The first Gatling gun was invented by Dr. Richard J. Gatling and patented November 4, 1862. This gun consisted of six barrels which were rotated by turning a crank. The charges were loaded in steel cylinders with percussion caps in place. The steel cylinders were fed from a hopper and placed in prolongation of the barrel, then fired and kept in prolongation (to prevent hang fires) for one turn, then dropped out. This gun was later modified to use metallic cartridges. The Gatling gun was demonstrated to the Federal forces by the inventor and his representatives by taking it to the front and shooting at the Confederates. It had a rate of fire of about 125 rounds per minute. It was not adopted as standard during the Civil War, but was adopted by this country and almost all foreign armies, except Germany and France, shortly after the Civil War.

The Gatling gun was the principal machine gun of the world for nearly 40 years, until displaced by single barrel guns operating on the recoil principle (both short and long), invented by Maxim in 1884, and the gas operated gun, invented and manufactured by Browning in America and by Baron Von Odkolex and Hotchkiss abroad. Another type was developed by Lewis, which fed from a drum instead of a belt as in the Maxim and Browning types. Maxim and Gatling guns were used in the Spanish-American and Philippine campaigns. During the World War many types of machine guns were made. Guns of the Browning type are generally favored now and four types are in current production—22 caliber, 30 caliber light and heavy, and 50 caliber anti-aircraft and anti-tank.

CANNON.

Muzzle-loading smooth-bore, muzzle-loading rifled, as well as breech-loading rifled cannon, were used during the Civil War by both sides. This war demonstrated the great superiority of breechloading rifled cannon, as

well as breechloading small arms. The great field gun of the Civil War was known as "The Swamp Angel" and was used to bombard the city of Charleston, S. C. It had a range of about five miles. All cannon used were slow firing, since recoil mechanisms were not used and the gun had to be pushed up and relayed for each shot. The cannoneers had to take cover before firing to keep the gun from jumping on them.

Artillery developments since the Civil War have been most numerous. The greatest single development has been the universal adoption, about 1890, of recoil cylinders to cushion the shock of firing. Great improvements have been made in breech construction, barrel construction, and in steels for fabricating cannon. Sights have been improved.

Mobile trench mortars of two types have been developed. The 81-mm. trench mortar obtains true flight by vanes on the base of the shell. The 4.2-inch chemical mortar obtains true flight by means of an expanding base which enables the mortar to be loaded from the muzzle for rapid fire, but a centrifugal motion is imparted to the shell by the rifling on the same principle as the Minié ball from the 1863 Springfield rifle. Both of these light mortars are equal in accuracy and fire power to field guns of the Civil War period.

Cannon of many types from 37-mm. to 16-inch are provided, each mounted and designed for a specific purpose.

As a result of the numerous improvements in cannon design, propellants, and materials of construction, both the range and accuracy of present cannon have been enormously increased over Civil War days. During the World War "The Paris Guns" fired 367 shells into Paris from the German lines, the maximum range used being about 74.6 miles. "The Swamp Angel" burst after firing a small number of shots into Charleston at a range of five miles. Thus one gets some idea of the advance of the artillery art since the Civil War.

ROCKETS.

The introduction of rifled breechloading cannon in the Civil War killed rocket development as an offensive weapon. Up until then rocket batteries were much used in the armies of Europe and especially in England. Rockets outranged and were more accurate than artillery then in use. There are a handful of us in the Army who believe the rocket is capable of great development as a military weapon, but nothing is being done except by wild-eyed professors who want to shoot the inoffensive moon with this magical gun. They thus bring derision on themselves as well as on the rocket.

EXPLOSIVES.

Black powder was the only propellant and explosive used during the Civil War, except mercury fulminate for primers. At that time many other explosives, such as nitroglycerine, dynamite, and nitro-starch were known to chemists. Guncotton had been discovered fifteen years prior to the Civil War by Schönbein, but had not been stabilized and made safe to handle until 1867 by Abel. Trinitrotoluene was discovered during the Civil War by Wilbrand, but the author has found no case in which it was used.

Since the Civil War, methods of manufacture have been greatly improved for the explosives known then, and new explosives have been discovered and satisfactory methods for their manufacture worked out. We mention only a few explosives developed since the Civil War.

Bulk smokeless powder—Schultz—1865.
Picric acid—Hausman—1878.
Ballicite—Nobel—1888.
Cordite—English army—1888.
Pyrocellulose smokeless—Mendelejef—1889.
Flashless smokeless non-hydroscopic powder—still under development.

Explosives are now known which possess many different degrees of sensitivity, brisance, temperatures of detonation, and other properties so that a particular explosive can be found for any special need. Probably greater changes have come about in explosives than in any other military weapon since the Civil War. Explosives have merely marched ahead with all other branches of chemistry, both theoretical and applied. The availability of huge tonnages of explosives is an excellent example of the influence of industrial development and scientific research upon the trend of modern warfare. For instance, the development of ammonia synthesis by Haber and his colleagues placed Germany in a position to manufacture nitric acid, hence all varieties of explosives from raw materials abundant in the Fatherland. Without this manufacturing process, Germany could have continued the World War for only a short period. The development of satisfactory substitutes capable of being made from cheap abundant raw materials is one of the most important steps in the preparedness program of any nation today.

TANKS.

Heavily armored and armed elephants and chariots were the tanks of antiquity. They were used in exactly the same way as modern tanks and armored cars; namely, to penetrate the enemy line and open a path for the advance of friendly troops. Such weapons were not used in the Civil War. A weapon of this character has been forced on modern armies by the invention of barbed wire by Lucien B. Smith in 1867 and the design of a practical wire of this type and machinery for its construction by Glidden and Vaughn in 1874. A modern position defended by barbed wire entanglements and rapid firing guns of all calibers is something that our grandfathers in the Civil War did not have to tackle.

The controversy as to who invented or developed the modern tank goes merrily on, but the weapon is here to stay until a more effective means of getting over barbed wire entanglements is found. Tanks, like the three bears of the nursery story, may be classed as big tanks, middle sized tanks, and baby tanks. Each one has a special purpose to perform. Each one has undergone numerous changes in the past 17 years and is destined to undergo as many more changes in the immediate future. Armored cars may be considered as special tanks.

AVIATION.

General Fitz-Porter made daily observations at 3000 feet altitude from a captive balloon at Yorktown in 1862. One day the ropes parted and his balloon drifted over the Confederate lines for an hour or so, then moved back over his own lines and descended until the trail ropes could be grasped by his men and the balloon pulled back to the ground. The first anti-aircraft artillery fire was delivered against this balloon during the first 300 feet of its ascent and the last 300 feet of the descent. The guns could not be elevated enough to reach the balloon when it was high in the air. Very considerable use was made of aerial observation by both the Confederate and

Federal forces, considering the difficulties involved. For instance, the Confederates constructed a balloon in 1863 by confiscating all the silk dresses in Richmond. Gas for inflating the balloon was available only in Richmond, hence the balloon would be inflated there and towed out by train or boat to the location at which it was desired to use it for observation. The compressed gas industry was not then in existence so that balloon observation was not generally possible. Yet the principle of its use was fully understood as the following statement by General Alexander, of the Confederate Army, shows: "Even if the observer never saw anything, the balloons were worth all they cost for the annoyance and delays they caused us in trying to keep our movements out of sight." The development of modern observation aviation has been based upon the principle thus stated.

Military balloons became a recognized part of practically all armies about 1870-80 for observation purposes.

Everyone is familiar with the rapid development of aviation since the Wright Brothers flew the first airplane 260 yards at Kitty Hawk, N. C., in 1903, and the first modern dirigible was designed and flown three miles by Count Zeppelin in Germany in 1900. The perfection of the internal combustion engine and strong light materials of construction have made these latter developments possible. From these humble beginnings, modern aircraft have developed enormously in speed, maneuverability, ceiling, useful load carried, and radius of action.

Airplanes are new military weapons. A great deal of misconception exists as to their true function in a modern army. They are a part of the military team and must do the job for which they are best fitted, viz.: (a) keep a continual watch on the enemy troops; (b) strike the enemy air corps on the ground or in the air; (c) attack ground troops and enemy works beyond artillery range.

The weapons of aircraft are machine guns, explosive and chemical bombs, and special apparatus for disseminating gases and smokes.

In the popular press, it is taken for granted that aircraft will be used to attack cities and civilians back of the enemy lines as was the case during the World War. In military circles (at least in our army) it is taken for granted that airplanes will have plenty of suitable targets within the enemy lines and the air effort will be directed against targets of military importance.

CHEMICAL WARFARE.

Chlorine, phosgene, chlorpicrin, mustard gas, white phosphorus, incendiary mixtures, and several other substances suitable for use in chemical warfare were known to chemists at the time of the Civil War. Most of these substances were laboratory curiosities then and could not be obtained in sufficient quantity for military use. Chemical industry was practically nonexistent in the South and was developed to only a rudimentary state in the North; hence the manufacture of black powder taxed both sides to the limit. Most of the black powder had to be imported.

Incendiary fillings for shells from "The Swamp Angel" were used against Charleston and were so effective that the Confederate commander, General Beauregard, addressed a letter to the Federal commander, General Gillmore, and advised him that he, General Gillmore, "would get a bad eminence in history for violating the laws of war." Smoke from damp hay and grass was used several times and cavalry was used frequently to stir up dust clouds to hide troop movements. The use of screening smoke was suggested to President Lincoln by Professor Sheppard, of Yale University, but no use

was made of the suggestion. A gas mask had been invented and patented by Lane in 1850. Thus chemical agents and a defense against chemical warfare were both known at the time of the Civil War, but this weapon could not be employed because of the lack of development in the commercial chemical industry.

Chemicals in the form of incendiaries and burning compounds to produce sulphur dioxide were much used by ancient armies and navies, but such weapons gradually fell into disuse because an equal effort expended on some other weapon produced greater damage to the enemy. However, with the enormous growth of chemical industry, the supply of large tonnages of effective chemicals for military purposes became possible for the first time during the World War.

An enemy securely dug in behind barb-wire entanglements is exceedingly hard to drive out. The barbed wire stops advancing infantry where they can be slaughtered by a few men armed with machine guns. Trenches and dugouts afford excellent protection against high explosive shell. Under such conditions, hundreds of artillery shell were required for every man killed. Hence the defense became almost impregnable. Then Fritz Haber introduced gas as the weapon to go through barbed wire, sink into trenches, and shoot around the corner. The French had toyed with tear gas in grenades and shells as an adjunct to trench raids, but had not seriously used chemical warfare methods.

On April 22, 1915, the Germans released 180 tons of chlorine in 6000 cylinders on a 6-kilometer front near Ypres, Belgium, and killed 5000 allied soldiers and sent 15,000 to the hospital. In the World War, on the average, it took 800 high explosive shells or 28,000 rifle and machine gun bullets to kill a soldier, or about 200 high explosive shells to wound a soldier and send him to the hospital, so any sensible person could see in chemical warfare a much more economical means of disabling the opponent.

Following chlorine, came phosgene, chlorpicrin, irritant smokes, and finally mustard gas, each one more difficult to protect against than the one preceding. An analysis of the German artillery-mustard gas shoots against the A. E. F. shows that from 5 to 12 shells were required to get a hospital casualty when green troops were attacked, and about 60 shells produced a casualty when seasoned troops, possessing a high gas discipline, were attacked. Naturally, the use of mustard gas increased. It was more effective.

Smoke, or artificial fog, came to be much used during the World War to prevent aimed fire being brought against infantry crossing open ground. These smoke screens reduce the percentage of hits of both sides, but the man on the outside of the cloud shooting at the unseen man in the cloud will hit four times as often as the man in the cloud strikes the target in the open. It is interesting to note that some of our own regiments in Cuba, who were armed with the black powder rifle, had been shot to pieces and forced to retire from the field by Spaniards using smokeless cartridges in Mauser rifles. Thus it becomes good business to put a smoke on the enemy during your approach and fire action, then have the smoke lift about the time of the final assault.

During the World War a tremendous amount of research effort was expended on finding new and more powerful gases, perfecting them, manufacturing and loading known gases into suitable munitions, and working out new munitions and new uses for the known agents as well as ways of protecting our own troops from enemy gases. At one time over two thousand people were employed on chemical warfare research by the United States alone. At first this effort was scattered under the authority of the Ordnance Department, the Engineers, the Medical Department, and the Signal

Corps. In order to accomplish the work in the shortest possible time, a unified service, the Chemical Warfare Service, was created to handle the entire problem.

As a result of the tremendous research effort during the war, Lewisite (β chlorvinyldichlorarsine) and Adamsite (diphenylaminechlorarsine) were discovered and methods for their manufacture and dissemination were worked out. A good gas mask was designed. Methods of activating charcoal and the preparation of other chemicals for the gas mask canister were found and about 5,000,000 gas masks made and sent to France for the use of the A. E. F., along with some 9000 tons of toxic gases and smoke materials.

Since the World War, a number of manufacturing operations have been much improved, some new munitions have been perfected, and a new liquid smoke agent discovered which is suitable for use by airplanes in laying down smoke screens to blind infantry and anti-aircraft artillery. The World War type of gas mask has been improved and a new type which enables the wearer to carry on a conversation or give commands has been developed.

No agent, suitable for use in the field, more powerful than Lewisite, mustard gas, hydrocyanic acid, or Adamsite, nor hotter than thermite has been discovered since the World War in this country or any other country so far as we know. Better gas protection is available now in all armies than was the case at the close of the World War. All armies realize the value of screening smokes and have developed suitable weapons and tactics for its use.

In the British War Office publication, "The Medical Aspects of Chemical Warfare," the following statement is found: "In the case of mustard gas, the number of casualties to be expected must to a great extent depend upon whether the military situation demands traversing or holding for a time a contaminated area. Should such a situation arise, medical units must be prepared to deal with much larger numbers of casualties than those allowed for when only weapons other than chemical are used."

The power, possibilities, and limitations of chemical warfare have been greatly distorted by partisans, for and against, and by ignorant journalists seeking to create a sensation. The truth is that chemical warfare is merely a weapon. This weapon is tremendously effective when used at the proper time and place.

As long as chemical warfare is the most effective weapon for certain purposes, it will continue to be used. The United States is not bound by any treaty to prevent the use of this weapon. There are ample raw materials and manufacturing and laboratory facilities to enable this country to use chemical agents in any quantity desired.

CONCLUSION.

In spite of military conservatism, great changes have been made in military weapons since the Civil War. Fire power has been enormously increased by the universal adoption of magazine and automatic rifles and by machine guns. Range, accuracy, and striking power of artillery are far beyond the dream of the Civil War cannoneer. High explosives, barbed wire, fighting aircraft, tanks, chemical warfare, are all new weapons which the Civil War commander did not have to consider. The result of all these changes is to make war much more complex. It requires a more thorough training and greater specialization on the part of officers and men alike; it is faster moving; it is more dependent on material and less on manpower than the war so ably carried on by Lee and Grant.—"The Military Engineer," Sept.-Oct., 1934.

Footnote. The views expressed in this article are those of the author and not necessarily those of any branch of the War Department.

WELDS FOR HIGH-PRESSURE, HIGH-TEMPERATURE PIPING.

Abstract of a paper before the American Welding Society giving results of tests on welds made under field conditions in connection with steam piping for the rebuilding of the Connors Creek Station of the Detroit Edison Company. X-ray and metallographic examinations, short-time tensile tests, impact tests and creep tests all showed satisfactory results.

At the fall meeting of the American Welding Society, held in New York, October 1 to 5, a paper by A. E. White, D. H. Covey and C. L. Clark described an examination of welds made under field conditions for high-pressure, high-temperature piping. These tests were made in connection with the rebuilding of the Connors Creek Station of the Detroit Edison Company to permit operation of the new section at 650 pounds and 850 F., the plant having been built originally for 225 pounds and 650 F. steam temperature.

Fusion welding, by the direct-current, metallic-arc process, is being employed for main and auxiliary superheated steam piping for the above mentioned steam conditions and for boiler feed piping which operates at 1000 pounds per square inch pressure and 385 F. The main superheated steam piping is especially noteworthy in that there are no flanged joints between the superheater outlet header and the inlet end of the turbine stop valve, all valves except the turbine stop valve being of the welding-end type.

The decision to adopt fusion welding to the extent indicated was arrived at only after extensive investigations had indicated that sound reliable welds could be produced under field conditions by welders employed by the company's Construction Bureau. Preliminary tests were directed toward determining the most satisfactory form of bevel, the proper clearance, proper electrode sizes and the effect of such operations as peening and stress-relieving. Following these tests, two welds were made under conditions duplicating field operations and submitted to the Department of Engineering Research of the University of Michigan for various destructive tests.

These two samples involved a pipe-to-pipe weld and a pipe-to-casting weld, the latter because it was proposed to use welding-end valves. The pipe used was 16-inch seamless steel pipe with the following analysis: carbon 0.33, manganese 0.75, silicon 0.06, aluminum (metallic) 0.04, chromium 0.06, phosphorus 0.01 and sulphur 0.02; all percentages being by weight. The casting was a 16-inch ring of the same wall thickness as the pipe and showing the following analysis by weight: carbon 0.24, manganese 0.62, silicon 0.36, chromium 0.82, nickel 1.19 and molybdenum 0.40.

The pieces were so assembled as to require welding in the flat, vertical and overhead positions. The welds were stress-relieved by heating with electric induction to a temperature of 1100 F. for one hour.

The tests to which the welded as well as the original pipe and castings were subjected, included X-ray and metallographic examination, tensile and impact tests at both room temperature and 850 F., creep tests at 850 F. and temper-embrittlement tests.

X-ray examination of the pipe-to-pipe weld showed 60 per cent of the circumference entirely free from defects, as was 25 per cent of the pipe-to-casting weld. The degree of porosity observed in the remaining sections of these welds was considerably less than the maximum allowed by the A. S. M. E. Boiler Code for Class 1 fusion welding.

The photomicrographs showed the original pipe to possess a somewhat coarser grain than is sometimes found in pipe material, but the structure of the weld proper was exceedingly fine grained.

Physical tests on the welded pipe-to-pipe specimens and on the welded casting-to-pipe specimens were both found satisfactory. They showed good

tensile strength, good yield stress, good proportional limit values and excellent ductility. In only one test was the ductility, as measured by the per cent elongation, low and in only three tests was the reduction of area not up to what it should be. In two of the specimens from which these values were obtained there was evidence of slight porosity which would account for the low ductility values.

Impact tests were made at 80 F. and 850 F. on the original pipe and casting material as well as on the welded specimens. While satisfactory, the test at 850 F. showed impact values for the pipe material and the welded specimens to be considerably under those obtained at 80 F. This was to be expected and was probably due to the fact that at this temperature the metal shows its lowest, or approaches its lowest, resistance to impact. Even at this temperature the material possesses a sufficient degree of impact resistance to render it satisfactory for the majority of commercial operations.

Creep tests were made on the original pipe, pipe-to-pipe and casting-to-pipe speciments at 850 F. The loads employed were 7000, 10,500, 12,000 and 15,000 pounds per square inch. In practically all cases, except under a stress of 12,000 and 15,000 pounds, the specimens showed little, if any, creep and little creep was shown at 12,000 pounds. The values obtained showed that the materials have a satisfactory resistance to creep for the purpose intended.

The short-time test was conducted by heating impact specimens of the various materials at 850 F. for half an hour and then air-cooling one lot and water-quenching the other; also by taking additional specimens and heating them for 48 hours at the temperature of 850 F. and then air-cooling one set and water-quenching the other. If the samples which are water-quenched show values decidedly under those obtained from air-cooling the material is considered to be subject to temper-embrittlement. In all cases, the drop in impact value due to water-quenching was not sufficient to justify any conclusion that these materials were subject to temper-embrittlement.

CONCLUSIONS.

On the basis of the results obtained from the metallurgical examination of the proposed pipe material for the main steam lines of the Connors Creek Station, the following conclusions may be drawn:

1. The X-ray examination showed that the welded sections were of a satisfactory quality.
2. The metallographic examination of the welded pipe-to-pipe and the welded casting-to-pipe sections showed the welds to be of an excellent type. The grain size was unusually fine in the welded sections, due doubtless to the method of welding employed.
3. The short-time tensile tests at room temperature and 850 F. showed all of the materials to possess a suitable combination of strength and ductility. The results obtained from the welded specimens were suprisingly good.
4. The impact values for all the materials tested were satisfactory.
5. The creep tests indicated the original pipe material as well as the welds to possess a sufficient resistance to creep. In fact, even under a stress of 15,000 pounds, an elongation of but from 1.1 to 1.5 per cent would be expected in 100,000 hours.
6. The temper-embrittlement tests may be said to be negative.

In conclusion, it is believed that the plain-carbon steel of the type tested and the Alloy H castings will render satisfactory service under the proposed operating conditions. These materials can be satisfactorily welded so as to produce the desired continuity of service without introducing operating hazards. This statement is made, of course, on the assumption that all the materials will be carefully inspected during production and installation.—"Combustion," October, 1934.

BOOK REVIEW

RIVETING AND ARC WELDING IN SHIP CONSTRUCTION, by COMMANDER H. E. ROSSELL, (CC), U. S. N., PROFESSOR OF NAVAL CONSTRUCTION, MASSACHUSETTS INSTITUTE OF TECHNOLOGY. SIMMONS-BOARDMAN PUBLISHING CO., 30 CHURCH STREET, NEW YORK—34 VICTORIA STREET, LONDON, S. W. I. PRICE $2.25.

REVIEWED BY H. W. HIEMKE.*

Commander Rossell's new book entitled "Riveting and Arc Welding in Ship Construction" presents the technology of modern ship fabrication in a realistic and unbiased manner. It should be of interest to structural and machinery designers as well as ship fabricators.

The summaries of allowable unit stresses in fillet welds, and the limits defined for spacing of intermittent welds are particularly valuable.

Commander Rossell's discussions of the design problems connected with welding fabrication are quite accurate; however, in his chapter on fundamentals of welding, a number of inaccuracies have crept in. For example, on page 85 he states "A narrow zone of the base metal adjacent to the bond has been subjected to a temperature of about 1000-1300 degrees Centigrade. The metal has been changed thereby to a coarse grained structure." In support of this statement, a macrograph of a weld is reproduced (p. 86). This structure is undoubtedly obtained when the weld is executed in the manner described "A one-layer continuous weld in a ½-inch plate." However, it is rarely the practice on ship plate to execute a weld in ½-inch plate in one layer. Such a weld would require at least four beads, and the effect on the structure of the adjacent metal would be quite different from the picture shown on page 86 of Commander Rossell's book. In fact, due to the more rapid cooling rate

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of small beads, and the layer-annealing effect of successive beads, the structure adjacent to the weld will be refined rather than coarsened.

The fears expressed in the paragraph entitled "Effect of weld across plate" should be allayed by this explanation: On page 84 the author describes the effect of welding with carbon steel electrodes on plates of various carbon contents. The statements made are correct, but they leave the general impression that the weldrod used has less effect on the resulting weld than the stock used. This is true only when single layer welds are made. On multiple-layer welds, the effect of the stock diminishes geometrically. Thus, if 40 per cent of the first bead is fused from the stock, the second bead will contain only 16 per cent of the base metal alloying elements, and the third bead 6.4 per cent. It is obvious that whenever a weld cannot be executed in a single layer, it is desirable to supply alloying elements in the weldrod so that the weld will be more homogeneous in its chemical and physical properties.

On page 82, the author describes some experiments conducted by Professor Hilpert on the size of particles in bare wire and coated wire arc transfer. The conclusion, as a result of this work, that the drops of metal in the coated wire arc are larger than in the bare wire arc is not in agreement with other carefully conducted researches on this subject. The large spheres which appear in the photographs of coated wire welding can be interpreted as bubbles, which burst across the arc at irregular intervals, the major arc metal transfer being accounted for by fine droplets, much smaller than the drops formed in bare wire welding.

The statements on pages 81 and 82 regarding shielded arc welding are likely to confuse the layman. The term "shielded arc" has been so universally applied to covered wire welding that it is more logical to consider the welding in gas atmospheres supplied externally to the arc as a subdivision, or imitation, of covered wire, or "shielded arc" welding.

On page 80, the discussion of A.C. welding has been rendered obsolete by recent developments. What the author says was true at the time it was written but very recently new A.C. equipment has been developed which operates on 70-100 volts, in order to counteract the high voltage argument which had always been raised against

it. Also, coated electrodes have been developed which work equally well on A.C. and D.C. for all-position welding. The disadvantage of A.C. on ship fabrication, and all field fabrication which still remains, is the high inductive power loss resulting from long welding leads crossing and surrounding iron structures.

On pages 107 to 109, the author develops the theoretical maximum stresses of fillet welds in tension only to show that the whole stress analysis is in error. It would have been better to omit this discussion, starting with Figure 136 of page 110 as an analysis of stress distribution.

KNOTS, TIES AND SPLICES.—A HANDBOOK FOR ALL WHO HANDLE ROPES. ORIGINALLY BY J. TOM BURGESS, REVISED AND REWRITTEN BY COMMANDER J. IRVING, ILLUSTRATED, NEW YORK, E. P. DUTTON & CO., INC.

Under the above title Commander Irving has disentangled the lore of ropes, and by a classification which separates and distinguishes bends, hitches, knots, splices, moorings, stops and slings, he has made the subject very interesting.

The instructions for the selection, care and suitability for special uses of cotton, hemp, manila and wire rope are comprehensive. There is included in the book a short chapter, with illustrations of gut leader fastenings, of interest to fishermen.

In this book, professional sailor, rigger and engineer will see many familiar rope practices described and illustrated. Also the amateur yachtsman, camper, and mountain climber will find much which will add to his skill and safety in rope uses.

G. L. S.

ASSOCIATION NOTES.

ANNUAL MEETING.

The Annual Meeting of the Society was held in Washington, D. C., on Monday, October 1, 1934, with Admiral William H. Standley, U.S.N., Chief of Naval Operations, our President, presiding.

The following were nominated for officers for the year 1935:

For President:

Admiral William H. Standley, U.S.N.

For Secretary-Treasurer:

Commander C. S. Gillette, U.S.N.
Commander R. W. Paine, U.S.N.

For Member of Council:

Captain N. H. Wright, U.S.N.
Captain B. H. Bruce, U.S.N.
Commander S. S. Kennedy, U.S.N.
Commander H. L. White, U.S.N.
Captain Henry Williams (C.C.), U.S.N.
Lieut. Comdr. W. C. Wade (C.C.), U.S.N.
Commander H. N. Perham, U.S.C.G.
Commander G. R. O'Connor, U.S.C.G.
Mr. P. N. Israel.
Mr. W. M. Corse.
Mr. J. F. Nichols.

Polls for election close on December 26, 1934.

ANNUAL BANQUET.

It was unanimously decided at the Annual Meeting to hold a banquet during the early part of 1935 in accordance with the usual custom of the Society. A committee composed of Captain H. G. Bowen, U.S.N., Commander C. S. Gillette, U.S.N., and Mr. P. N. Israel has been appointed to make preliminary arrangements.

MEMBERSHIP.

The following members have joined the Society since the publication of the last previous JOURNAL:

NAVAL.

Cavenagh, Robert, Lieutenant, U.S.N.
Chambers, George M., Lieutenant, U. S. N.
Davis, F. R., Lieutenant, U.S.N.
Morgan, Phillip S., Lieutenant, U.S.N.
Thornton, William N., Lieutenant, U.S.N.

CIVILIAN.

Crawford, W. W., 7116 Coles Avenue, Chicago, Ill.

ASSOCIATE.

Hiemke, Hugo, Bureau of Engineering, Navy Dept., Washington, D. C.

Homer, Arthur P., Washington Bldg., Washington, D. C.

Mark-Wardlaw, A. L. P., Engineer Commander, Royal British Navy.

Neiva, Rubens V., Lieutenant, Brazilian Navy.

Turner, Ernest G., 1445 Laudendale Avenue, Lakewood, Ohio.